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Journal

OF

The Royal Society

OF

Western Australia.

Vol. XX.

1933-34.

The Authors of Papers are alone responsible for the statements
and
the opinions expressed therein.

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1934.

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THE ROYAL SOCIETY OF WESTERN AUSTRALIA.

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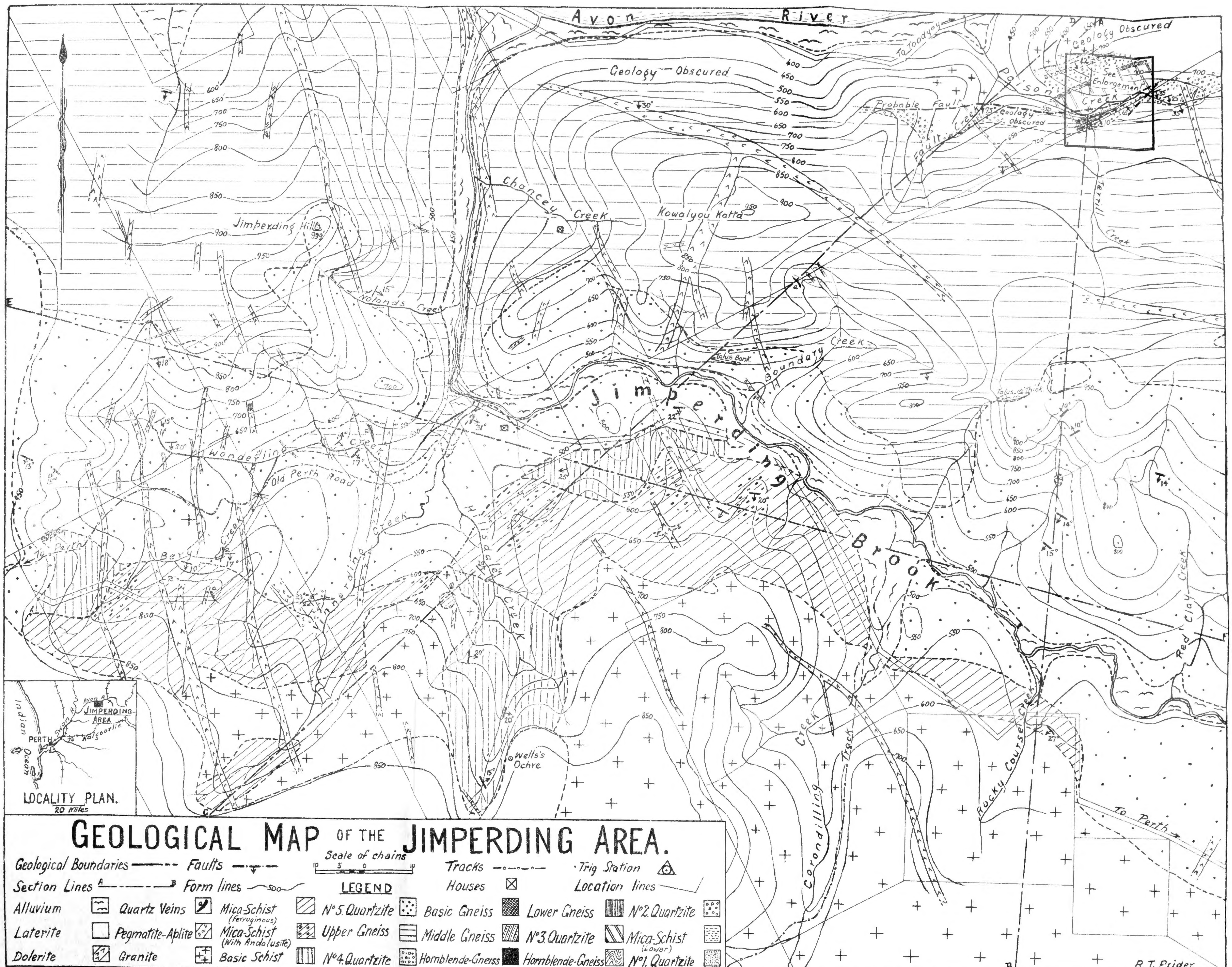

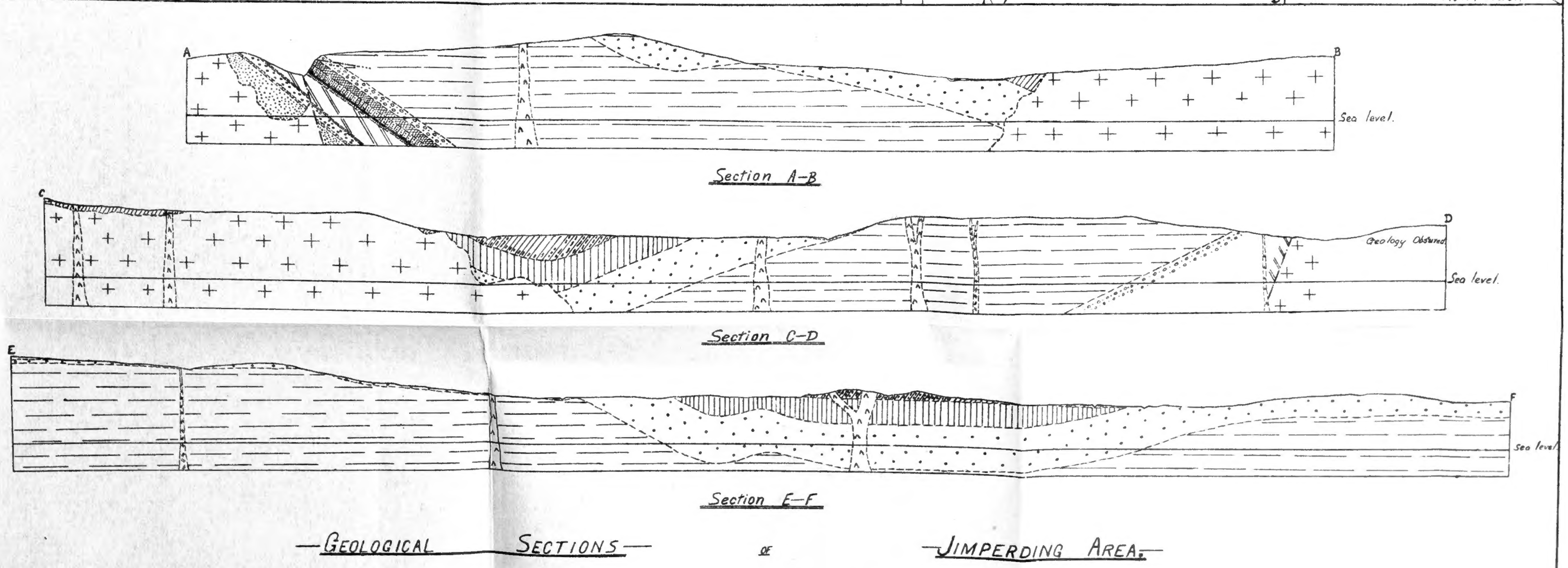

—GEOLOGICAL SECTIONS— OF —JIMPERDING AREA.—

0 1000 2000

Natural Scale of Feet

Legend as in Geological Map

VICTORIA

CONTENTS.

VOLUME XX.

ROYAL SOCIETY OF WESTERN AUSTRALIA.

ANNUAL REPORT OF THE COUNCIL FOR YEAR ENDED JUNE 30th, 1934.

Ladies and Gentlemen,

Your Council begs to submit the following report for the year ended June 30th, 1934.

In view of the difficult times through which we are passing the membership figures must be regarded as satisfactory. There are 95 ordinary members and 54 associate members as compared with 99 ordinary members and 57 associates on June 30th, 1933. In addition there are 9 honorary members and 6 corresponding members as well as 22 student members. During the year 3 ordinary members and 7 associates have been elected, while 6 associates have been transferred from associate to full membership of the Society. Mr. D. L. Serventy, who was elected a corresponding member during the tenure of his scholarship abroad, having returned to Western Australia, has resumed his ordinary membership. On the other hand, 12 ordinary members and 4 associates have resigned.

We regret to report the loss by death of Mr. Horace Thomas, B.A., a member who was always interested in the activities of the Society.

Council.—Eleven ordinary meetings and one special meeting of the Council were held during the year.

Finance.—The grant received from the Treasury during the year was at the rate of £80 per annum, and the Council wishes to express its thanks to the Government for the subsidy. Without the aid of the Government grant, the publication of papers in the *Journal* would have to be even more seriously curtailed than at present. During the year £140 15s. 1d. has been spent on printing and an expenditure of £80 has been authorised for printing papers in the current volume.

In the last annual report concern was expressed at the cost of printing papers from those student members of the Society who are also research workers at the University. It is the aim of the Council to encourage the publication of papers by students where they are recommended by the appropriate University Department. It is, however, necessary that the publication rights of ordinary members should not be jeopardised by this consideration. The Council has been in communication with the University authorities in connection with the matter, but so far it has been unable to reach a definite understanding. It has been necessary, therefore, to draft rules of publication, the aim of which is to conserve the financial stability of the Society while still extending publication rights (under certain conditions) to associate and student members of the Society.

Publications Committee.—Volume XIX. containing the proceedings and transactions of the Society for 1932-33 has been completed, issued to members and distributed in accordance with the exchange list. The preparation

of Volume XX., which is to contain proceedings for 1933-34, is well in hand. The Publications Committee has met regularly throughout the year and given serious consideration to all papers submitted for publication. In all cases opinions on the merits of papers have been obtained from authorities within the Society. In some instances papers have been referred back to authors for re-arrangement and substantiation of conclusions before being finally offered for publication. Every effort has been made to economise in printing space.

Twelve manuscripts have been submitted during the year under review, of which ten will be printed in Vol. XX. Of four contributions dealing with Western Australian material, one comes from the United States of America and three come from the Eastern States.

Revised instructions to authors have been prepared, together with the conditions under which manuscripts may be published, and have been distributed with Volume XIX.

Mr. B. L. Southern has again carried out the duties of editor, and the Council desires to express its appreciation of his work in that capacity.

The Council also wishes to express its appreciation to the Government Printer and his officers for the interest they take in the printing of the *Journal* and advice in the setting up of publications. Their ever ready assistance and co-operation have been invaluable to the editor.

Library.—The Society is in regular exchange with 144 institutions, 47 of which are in Australia, 17 in the United Kingdom, 17 in the Dominions of the Empire, 31 in the United States of America, 29 in Europe and 3 in Asia. For the information of members, a list of publications received in exchange for the *Journal* will be published in Volume XX.

Royal Society's Gold Medal.—Mr. W. M. Carne, the Gold Medallist of the Society for 1932-33, was presented with the Gold Medal, on behalf of this Society, by His Excellency Sir Ernest Clark, Governor of Tasmania, at the meeting of the Royal Society of Tasmania at Hobart on September 11th.

L. GLAUERT, President.

L. W. PHILLIPS.

F. G. FORMAN,
Joint. Hon. Secretaries.

ROYAL SOCIETY OF WESTERN AUSTRALIA.

STATEMENT OF RECEIPTS AND EXPENDITURE FOR THE YEAR 1933-1934.

Receipts.

GENERAL FUND—	£	s.	d.
Balance, 1st July, 1933	68	7	8
Subscriptions	162	16	6
Government Grant, July, 1933, to June, 1934	80	0	0
Author, Reprints and Refunds for half cost of blocks	37	10	1
Miscellaneous Receipts	2	5	0
Interest on Current Account	2	10	7
	£353	9	10

Payments.

	£	s.	d.	£	s.	d.
Petty Expenses, including Postages, etc.				12	17	9
Clerical Assistance				7	4	3
Stationery				0	7	0
Annual Meeting, Catering				7	0	0
" " Rent				3	3	0
" " Lantern				1	9	0
December Meeting, Catering				1	17	6
Museum Trustees, Rent				12	0	0
" " Attendant's Fee				8	2	6
Editor, Honorarium				15	15	0
Excursion Expenses				0	13	0
Medal, Balance of Cost				4	10	0
Transfer to Medal Fund				7	10	0
" Endowment Fund				25	0	0
Post Office Box, Rent				3	0	0
Government Printer—						
Journal XIX., completing	45	15	5			
Journal XX., part cost	94	13	2			
Notices of Meetings	2	14	3			
Miscellaneous Printing	3	1	10			
				146	4	8
Balance 30th June, 1934				96	16	2
				£353	9	10

Receipts.

MEDAL FUND—	£	s.	d.
Balance, 1st July, 1933	20	0	0
Transfer from General Account	12	0	0
Interest	0	3	3
	£32	3	3

Payments.

	£	s.	d.
Medal, W. M. Carne	24	10	0
Balance 30th June, 1934	7	13	3
	£32	3	3

ENDOWMENT FUND—	£	s.	d.
Balance, 1st July, 1933	132	6	0
Transfer from General Account	25	0	0
Interest	9	15	3
	£167	1	3

	£	s.	d.
Balance 30th June, 1934	167	1	3
	£167	1	3

£167 1s. 3d. placed on fixed deposit at Commonwealth Bank, Perth, on 12th June, 1934, for 24 months, bearing interest at $2\frac{3}{4}$ per cent. per annum.

SUMMARY OF FUNDS AT 30TH JUNE, 1934.

	£	s.	d.
Credit Balance, General Fund	96	16	2
" " Medal Fund	7	13	3
" " Endowment Fund	167	1	3
Total	£271	10	8

H. BOWLEY,
Hon. Treasurer.

Audited and found correct, with books, receipts, and vouchers produced, and we consider this a true statement of the Royal Society Accounts.

R. E. GATHERER,
THOS. H. WILSON,
Hon. Audtors.

Perth, 7th July, 1934.

ROYAL SOCIETY OF WESTERN AUSTRALIA

List of Members as at 1st July, 1934.

HONORARY MEMBERS.

Bird, Mrs. A. M.—The Old Farm, Albany.

Cooke, Prof. W. E., M.A., F.R.A.S.—c/o. J. A. Minchin, Esq., 46 Kent Terrace, Norwood, S.A.

Dakin, Prof. W. J., D.Sc., F.L.S., F.Z.S.—The University, Sydney, N.S.W.

Diels, Dr. Ludwig—Director of Botanical Garden and Museum, Berlin-Dahlem, Germany.

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Pritzel, Dr. E.—Str. 4, Hans Sachs, Berlin-Liehderfelde.

Thynne, Major R.

CORRESPONDING MEMBERS.

Alexander, W. B., M.A.—120 Croydon Road, Reigate, England; or Department of Zoology, University Museum, Oxford.

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Clark, J., F.L.S.—National Museum, Melbourne.

Herbert, D. A., D.Sc.—Department of Biology, University of Queensland.

Orton, A. A., B.A., M. Sc.—University of Otago, Dunedin, New Zealand.

ORDINARY MEMBERS.

Allum, Miss Enid I.—47 Outram Street, West Perth.

Anderson, Joseph—9 Mitchell Street, Mt. Lawley.

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Blatchford, T., B.A.—2 Lyall Street, South Perth.

Blix, K. J., C.E.—c/o. Chief Engineer, Ways and Works, W.A.G.R., Perth.

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Bourne, Geoffrey, M.Sc.—Institute of Anatomy, Canberra, F.C.T.

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Feldtmann, F. R.—Geological Survey, Perth.
Filmer, J. F., B.V.Sc.—Agricultural Department, Perth.
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Forman, F. G., B.Sc.—Geological Survey, Perth.

Gardner, C. A.—Agricultural Department, Perth.
Garner, W. B., F.C.S., M.P.S.—c/o F. H. Faulding & Co., Murray Street, Perth.
Gatherer, R. E.—Royal Mint, Perth.
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Lukin, Mrs M. R.—Roberts Road, Subiaco.

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Palmer, C. B.—C/o Parkerville Homes, Parkerville.
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Rockett, H. P., A.Inst.M.M.—Cue.
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Southern, Miss M. M.—Applecross.
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Wood, Miss M. E., B.A.—The University, Crawley.
Wood, W. E.—Inspecting Engineer's Office, Railway Department, Perth.

ABSTRACT OF PROCEEDINGS, 1933-34.

11th July, 1933

Annual General Meeting held at Karrakatta Club. Presidential Address: "Plant Response to the Dry Phases of the Climate of the South-West, Western Australia."

8th August, 1933

Paper—"A New Terrestrial Isopod from Northern Territory, Australia," Miss H. M. Barnes.

Lecture—"Some Recent Work in Psychology," Dr. H. L. Fowler.

12th September, 1933—

Lecture—"Principles Governing the Development of the Dairying Industry in Western Australia," Mr. G. K. Baron-Hay.

17th October, 1933

Lecture—"Observations made on a Recent Geological Excursion through Great Britain," Professor E. de C. Clarke.

21st November, 1933

Papers—"Contributions to the Mineralogy of Western Australia," Series 8, Dr. E. S. Simpson.

"A New Method for the Determination of Ferrous Iron in Refractory Silicates," Mr. H. P. Rowledge.

"Analyses of Collie Coals," Mr. H. Bowley.

12th December, 1933—

Papers—"Aboriginal Skulls in the Western Australian Museum," Mr. G. Bourne and Miss K. Mulcahy.

"An Abnormal Thyroid Gland found in a Lizard from Eclipse Island, W.A.," Mr. G. Bourne.

13th March, 1934

Lecture—"Modern Development in the Geological Exploration for Petroleum" Dr. Arthur Wade.

Paper—"Contributions to the Fauna of Rottnest Island, VIII. Apoidae," Tarlton Rayment, communicated by the President.

10th April, 1934—

Lecture—"The Relation between Nutrition and Fertility in Animals" Dr. E. J. Underwood.

Paper—"Contributions to the Fauna of Rottnest Island, IX.—The Ants," Professor W. M. Wheeler, communicated by the President.

8th May, 1934—

Paper—"The Mineralogy of the Fine Sands of some Podsols, Tropical, Mallee and Laterite Soils," Miss D. Carroll.

"The Palaeontology of the Plantagenet Beds of Western Australia," by Mr. F. Chapman and Miss I. Crespin, communicated by the President.

12th June, 1934—

"Discussion on Glaciation in Western Australia," contributed to by Messrs. F. G. Forman, A. Gibb Maitland and Professor Clarke. Mr. L. Glauert spoke on "Some Relics of Glaciation in England."

PROCEEDINGS—BIOLOGICAL SECTION.

During the year nine general meetings of the Section were held. From March of this year onwards Mr. G. Bourne has been absent in the Eastern States and Mr. C. Jenkins has occupied the chair in his stead.

OFFICE BEARERS:

Chairman	...	Mr. G. Bourne
Secretary	...	Mr. K. R. Norris

Abstract of Proceedings.

25TH JULY, 1934—

Elections and Exhibit evening.

15TH AUGUST, 1934—

Lecturettes—Miss J. Hearman: "Black Spot in Pears." Miss A. Baird: "Flora of Bayswater."

26TH SEPTEMBER, 1934—

Lecturettes—Miss K. Prendergast: "Development of External Features of Brachiopoda." Mr. C. Jenkins: "Inter-relationships of Birds and Men."

24TH OCTOBER, 1934—

Lecture—Dr. Breidahl: "Vitamins in Relation to Growth."

28TH NOVEMBER, 1934—

Lecture—Mr. G. Bourne: "Modern Biological Trends and some recent advances in Cytology."

26TH MARCH, 1934—

Exhibit Evening.

23RD APRIL, 1934—

Lecture—Mr. E. W. Bennett: "The Origins of Flowers."

22ND MAY, 1934—

Lecture—Dr. H. L. Fowler: "Dreams."

26TH JUNE, 1934—

Lecture—Mr. C. A. Gardner: "Some Characters of the Desert Flora of Western Australia."

The average attendance for the year was 12.

EXHIBITS.

The Publications Committee has decided, in future, to place on record in the Journal all important and rare exhibits displayed at general and sectional meetings. Exhibitors are requested to supply the Editor with the name, locality and date of discovery of specimens.

Reedia spathacea.—Complete plant from Walpole Inlet, Nornalup; C. A. Gardner, 10th May, 1932.

Apatised wood associated with minulyte, Dandaragan; Dr. E. S. Simpson, 13th September, 1932.

Porphry showing dendritic markings, Higginsville; L. Glauert, 11th October, 1932.

Ruellia primulace and *Babbagia acroptera*, Minilya River; C. A. Gardner, 13 December, 1932.

Swainsona McCullochiana, Ashburton; H. Steedman, 11th April, 1933.

Eucalyptus caesia, North Merredin; H. Steedman, 8th August, 1933.

Glauertia russelli, Loveridge, a new genus and species of frog, Gascoyne district; L. Glauert, 12th September, 1933.

Scyllarides squammosus (Milne Edwards), Shark Bay; L. Glauert, 17th October, 1933.

Garnet pyroxene, Rothsay; Dr. E. S. Simpson, 13th March, 1934.

Alectis ciliaris (Block)—Pennant Fish, Wembley Beach; found by A. Marsland, exhibitor, L. Glauert, 10th April, 1934.

Glacial Pebbles, Dandaragan sand plain; F. G. Forman, 12th June, 1934.

Macrozamia Dyeri (F. V. M.), fronds, nuts and living seedling, the latter growing in leaf axil of parent plant and showing juvenile leaves with terminal serrations, Esperance; found by K. W. McLean, May, 1934, exhibited Biological Section, 26th June, 1934.

CONSIDERATIONS OF THE PROBLEM OF CORRELATION IN STRATIGRAPHICAL GEOLOGY.

PRESIDENTAL ADDRESS

BY

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The accurate correlation of sedimentary beds is becoming more and more important as the methods of stratigraphical geology become increasingly refined, and yet, even to-day, mere lists of fossils are often quoted without any consideration being given to the value of the evidence presented by the various species employed.

With the passage of time we are apt to forget the admonition of Charles Lyell that the present is the key to the past—that the past can best be interpreted through a careful study of the present—though Lyell's statement is as true to-day as it was at the time when it was first uttered, about a century ago.

It may, therefore, not be out of place if, in my address to you this evening, I refer to the various factors which govern the dispersal, the distribution, nay, the very existence of marine organisms in the seas and oceans of to-day. Although it is no doubt correct to postulate that the tendency has been to pass gradually from the simple to the complex, we are justified in assuming that the well-being of a species has always been governed by external influences similar to those which are in operatioin on the earth at the present time.

It does not require an intensive scientific training to recognise the differences between the faunas of reefs and sandbanks, and any severe winter storm will prove to us, by the material thrown upon our ocean beaches, that the animals of the deeper waters are not identical with those normally inhabiting the beach shallows.

But the nature of the bottom and the pressure are only two of the many factors which govern the distribution of marine forms. We have also to deal with such matters as availability of food supply, competition, temperature, salinity, and condition of the water, whilst if we wish to consider the dispersal or migration of forms it is essential that we study distribution of land and sea, winds, ocean currents, the configuration of the sea bed and, last but not least, the capacity of the organism itself, its power to withstand external changes and, if it be a sessile animal, the duration of the free-swimming larval stage and the means of locomotion available to the organism.

The most obvious factor regulating the movements or dispersal of marine animals is the **distribution of land and sea.** Although at the present day over 70 per cent. of the earth's surface is covered with water, the conditions for migration in the arrangement of the oceans are not ideal. An interchange of surface faunas through Arctic seas can only affect the boreal forms. Whilst in the south the extensions of South America and South Africa are such that they cut off the warmer part of the Atlantic from the Indian and Pacific Oceans, the latter are connected through the Austro-Malayan archipelago. We, therefore, find many animals with an extensive range in the Indo-Pacific region absent in the Atlantic, where they may, however, be represented by some related form. Of the Cyclometopa of the Red Sea only two occur in the Atlantic, while the majority have a very wide range in the Indo-Pacific region.

The position and configuration of the land masses also affect the ocean currents and the winds, thus having an indirect influence upon the plankton and to a certain extent upon the neckton also, for many of these small motile forms are generally too weak to swim against the slowly moving waters with marked success. In the vicinity of coasts further complications may arise, particularly during the summer months; the sun, beating down on land and sea, warms the land more rapidly, causing the air to rise and thus inducing a sea breeze which affects the upper layer of the ocean and bears the heliotropic plankton on towards the shore. At night the position is reversed; the land cooling more rapidly than the water, a land breeze sets in; this, blowing in an off shore direction, carries the upper layer with it, which is now swarming with the negatively heliotropic plankton that began to rise to the surface as the power of the sun decreased, and reaches its maximum density at the surface about midnight.

It would seem that at the present time the plankton is seasonal and most abundant in colder waters. Whether it has always been so we cannot say, but it is probable that no change has ocurred since Palaeozoic times in a habit so widely distributed among marine organisms.

The contour of the ocean bed is a most important factor in the distribution of animal life. Next to the land we have the strip known as the tidal zone representing the area between high and low water marks—insignificant near Fremantle, where the rise and fall is small—but most extensive at Broome, where the rise is over 24 feet and the beach slopes very gradually. Beyond this is the zone known as the shallow sea which lies over the continental shelf, the drowned margin of the continents, extending out to sea to the hundred fathom line where it merges into the continental slope that passes more or less steeply into the deeper abyssal region. The width of this zone may vary from under 20 miles to over two hundred. This region of the shallow seas is of great interest to the geologist for, with a few exceptions, the animal life preserved in the rocks, so far known to us, consists of denizens of this zone and of pelagic forms from the higher layers of the open ocean which have drifted in shore from their normal habitat.

It is on the continental shelf that most of the sediments comprising Marr's belt of variables were laid down, though during periods of greater elevation they may extend some distance down the continental slope, when they form thicker accumulations like the Lower Ludlows of North Wales and the Lake District, and the Oxford Clay. Practically very little light penetrates to the 100 fathom level, even in tropical regions where the water

may be exceptionally clear. In muddy water sea weeds cannot exist below 10 fathoms; in clearer water they have been found to thrive at 30 fathoms, and healthy specimens have been dredged from a depth of quite 40 fathoms off oceanic coral reefs.

Taken as a whole the area of the shallow seas carries a fauna richer and more varied than any other area on the earth's surface. This is not surprising when we remember that Sir John Murray considered the area within his mudline the outer mudline of Marr—to be "the great feeding ground of the ocean." Beyond the continental shelf is the continental slope. This slope and similar areas around oceanic islands present greater variety than is to be found elsewhere on the ocean floor. Off large rivers detritus from the land forms the bulk of the deposit, at other places glauconite and phosphates occur though quartz and other terrigenous minerals may still predominate. In the abyssal regions, covering about one half of the earth's surface, conditions are more uniform, solar light is absent, the temperature is constant at approximately 32 degrees F., and the movements of the water so slow that there is little or no erosion. The organic deposits vary with the nature of the fauna in the layers above, and at the greatest depths far from land may consist almost entirely of the teeth of sharks and the ear bones of whales.

The bed of the ocean is, however, remarkably even; it has been called and undulating plain. The steepest gradients usually occur on the cont'nental slope between 100 and 1,450 fathoms, and on some coasts there appear to be submerged terraces or drowned valleys, which it has been shown are not always due to the action of rivers in former geological periods, but to submarine erosion. Isolated cones of all sizes are known and submerged plateaux or ridges often become important because of their effect upon ocean currents. The Wyville Thomson ridge keeps Arctic waters of less than 45 degrees F. out of the North Sea, the barrier at the Straits of Gibraltar prevents the eastward movement of the lower water of the adjacent Atlantic, and the submerged ridge to the north of the Celebes Sea enables this body of water to maintain an even temperature of 39 degrees F. to a depth of approximately 2,000 fathoms.

From these remarks it is not surprising to learn that neither at the surface nor in the waters beneath is the water of an even temperature.

Broadly speaking **the temperature** at the surface depends upon the geographical position. In the equatorial region there is a broad band where the surface temperature exceeds 80 degrees F., whilst in the seas of the Arctic and Antarctic regions it is icy cold. The intervening waters range in temperature between these extremes, although the bands are not of equal width and are often distorted by the effects of ocean currents, which may be limited to the surface, or be part of that circulation whose permeation through the whole mass of the waters is so essential to animal life in the depths by providing the necessary oxygenation.

The movements of the surface currents, which may be felt to a depth of several hundred fathoms, no doubt had their origin in the prevailing winds, whilst their courses are profoundly influenced by the distribution of land and sea. In the warmer latitudes the north-east and south-east trade winds drive the water westwards on to the eastern shores of continents where considerable masses of warmer water are banked up. Evaporation increases the density, and so these heated masses extend to the bottom where

the lateral flow has led to a marked increase in area. The westerly movement of waters from the western coasts of continents is responsible for that upwelling of colder water so marked off America and Africa but less evident off our own shores.

South of the three southern continents the prevailing westerly winds of the "roaring forties" move round the globe in an unending procession, owing to the absence of intervening land. Their equivalents in the northern hemisphere are the westerly winds of the temperate portions of the Atlantic and Pacific oceans. It is the influence of this westerly wind represented by the Gulf Stream and the Gulf Stream Drift that so profoundly affects the temperature of European seas and brings to the shores of the British Isles and Norway pelagic organisms whose normal habitat is in the tropical or sub-tropical Atlantic. *Physalia*, *Velella*, and *Porpita* among the Siphonophores, the gastropod *Ianthina* and the cephalopod *Spirula* are well known examples.

Compensating movements of colder waters in the direction of the Equator are the Peru current, the Falkland current, and the Benguela current in the southern hemisphere, the cold Japanese current in the North Pacific, with the East Greenland current and the Labrador current in the North Atlantic. A striking example of the influence of the temperature of the water upon distribution is the range of *Littorina littorea* in the Western Atlantic. The natural home of the periwinkle is north-western Europe as far south as the Gulf of Gascony, beyond which it cannot pass because the warmer water is fatal to the floating ova. (Pelseneer.) In 1855 the species was noticed at Bathurst, New Brunswick, whither it had been brought by shipping; by 1868 it had spread to Nova Scotia, later it was reported from Maine, and by 1880 had reached Newport, Rhode Island, and New Haven, Connecticut, beyond which it had not been able to spread because it had reached its temperature limit.

An instance of the effect of a sudden appearance of cold water is afforded by the practical extermination of the Tile-fish, *Lopholatilus chamaeleonticeps*, off southern New England, U.S.A., in the spring of 1882. This fish was of considerable economic importance and its disappearance was a disaster; the loss has fortunately been repaired in the intervening years, for to-day the fish is as plentiful as it used to be when first discovered by trawlers at the edge of the Continental Shelf in 1879.

Sir John Murray has shown that the deposits of tests of pelagic foraminifura are most abundant on the sea floor below points where warm and cold currents meet. Other members of the plankton and nekton also are adversely affected by the meeting of warmer and colder waters.

The daily variation which may exceed 100 degrees F. on land is almost negligible at sea; the observations made in the North Atlantic by the Challenger on 126 days gave the mean of 3.21 degrees F. whilst that of the surface water showed less than 1 degree. An examination of the complete results led Murray to the opinion that nowhere in the open ocean does the mean daily fluctuation of the temperature of the surface water amount to one degree. The *annual* range, however, may be considerably greater; over vast tracts of tropical and polar waters it does not exceed a few degrees, whilst in places occupied by warm or cold waters according to the season the difference may amount to 50 degrees. The influence here upon marine

organisms must be of importance and probably helps to account for the marked seasonal variation in the plankton and of most animals directly or indirectly dependent upon the plankton for food, even if they themselves are not so susceptible, which rarely occurs.

The temperature in the main mass of the oceans below the relatively thin surface film is less subject to change. In the tropics the fall is at first rapid and then more gradual towards the bottom in deep water. This is the general rule except in closed seas or where barriers occur to interfere with the normal circulation of oceanic waters. The seasonal variation, small as it is, even in the surface layer becomes less and less with depth and seems to disappear entirely at 100 fathoms, although there are occasional exceptions.

At a depth of 100 fathoms, between 30° N. and 30° S. the water in the Western Atlantic is much warmer than that near the African coast, owing to the slow sinking of the denser warm water as it approaches the American coast. On the whole, the North Atlantic is much warmer than the South; at 100 fathoms the proportion of warmer water is greater and the maximum temperature 70 degrees instead of 63 degrees.

At 300 fathoms the difference between the North and South Atlantic is even more marked. In the South but a small area reaches 48 degrees, whilst in the north water of this temperature extends over about half the ocean and encloses two warmer patches, in one of which 63 degrees is registered.

When water at the depth of 500 fathoms is considered it is found that, whilst the whole of the South Atlantic is below the mean, nearly the whole of the North Atlantic is above it, the highest temperature being now recorded from the eastern portion just west of the Straits of Gibraltar, as a result of the warm water flowing from the Mediterranean. At 900 and 1,500 fathoms the influence of the water from the inland sea can still be traced but at 1,500 and 2,200 the temperature is almost uniform throughout the ocean from east to west. When the bottom is reached we still have warmer water in the North Atlantic, for records show that it exceeds the bottom waters of the South Atlantic and Indian oceans by about 2 degrees, the result of the movement northwards of the cold water of the Antarctic, a corresponding creep from the Arctic being intercepted by the Greenland-Shetland ridge and the Bering Straits shallows.

To sum up the position briefly, whilst at the greater depths, which do not concern us to more than a very limited extent, uniformity within a few degrees is very widely, if not universally, distributed, in the higher levels considerable ranges have been observed which are increased still further when the upper layer is taken into consideration. This marked difference cannot fail to become a serious limiting factor in the distribution of organisms unable to withstand marked changes in temperature. On the other hand, large areas presenting almost identical conditions must assist the dispersal of forms capable of taking advantage of the opportunity. The marked resemblance between faunas of Arctic and Antarctic seas—"Bi-polarity"—has been explained as being due to the presence of low temperature waters in ocean depths rendering a mingling and migration of forms possible. On the other hand an alternative, that polar faunas originated at ocean depths whence they moved to the Arctic and Antarctic has now many supporters.

Temperature is by far the most important limiting factor in the geographical range of coastal fishes in the seas of to-day. In the tropical zone the

coastal species of the Atlantic and Indo-Pacific represent two distinct regions, for though the same genera may occur in both, the species are nearly always different, indicating the same distant origin of both faunas, but suggesting little if any migration from one ocean to the other. An excellent example of temperature control in both northern and southern waters is afforded by the range of *Sardina* whose species are limited in their distribution by the mean annual surface isotherms of 68 degrees F. maximum and 54 degrees F. minimum. (Norman.)

According to Kyle fish ova are very sensitive to changes of temperature though almost immune to such chemical stimuli as salinity, etc. The eggs of the Herring, which at 39 degrees F. take about 40 days to hatch out, will pass through the same stages of development in 8 days if the water is considerably warmer (54 degrees), the explanation being the increased rate of metabolism.

Van t'Hoff's law, which is strictly applicable to plants, stipulates that the rate of the chemical reaction is doubled or trebled when the temperature is raised 10 degrees C. (18 degrees F.) and the evidence available shows that it applies to animals also. There are in the polar regions many species which pass the whole of their lives in water below 32 degrees, whilst in the tropics others of the same groups live in water of 80 degrees. Further, whilst in colder waters a species is often represented by swarms of individuals it is the rule that warmer seas present a greater abundance of genera and species but a marked scarcity of individuals of each. An examination of the vast number of a species brought up in a haul in Artic waters generally reveals the presence of all stages of development, eggs, young and adult, and from this Murray assumes that some of the adults may be as much as 10 or 20 years old. In the tropics, on the other hand, where the water is warmer, the ages could be counted in months, weeks, and even days, because of the increased rate of chemical activity and as a consequence numbers would be reduced by earlier death.

Among Acanthopterygian Fishes, Star Jordan found that the majority of tropical species possess 24 vertebrae whilst in temperate and colder seas the number tended to increase. The Scorpaenids of the tropics have 24 vertebrae, those of Japanese seas 27 and the only known Antarctic *Sebastes* possesses 39. The same peculiarity has been observed among Labrids and is particularly noticeable in the Pleuronectids where the numbers vary from 35 in species off Southern California and Florida to 49 and 50 in forms from the Bering Sea, the North Pacific and North Atlantic.

As has already been indicated **salinity**, which is closely bound up with temperature, is by no means regularly disseminated in the ocean. The question whether the Palalozoic seas had a lower salinity than those of to-day is not of serious moment, for it is most probable that uniformity did not exist in those distant days, for winds, surface currents and deeper ocean movements must have been present then as now. In any case, the decrease or increase would have proceeded so gradually as to have been practically imperceptible, even after intervals of thousands of years, so that the changes will have passed unnoticed by the short-lived organisms of ancient seas.

Variations in salinity, both seasonal and regional, have been noticed by all research expeditions investigating the physical condition of the oceans,

although it is the general opinion that the composition of sea-salt is constant within very narrow limits whether collected at the equator or in the polar regions, whether obtained at the surface or drawn from the great ocean depths. Chlorides and sulphates of sodium, magnesium, potassium and calcium are the principal dissolved salts, common salt—sodium chloride—being by far the most abundant, making up nearly 78 per cent. of the whole. There are also small quantities of calcium carbonate, so necessary to the countless lime-secreting forms, and magnesium bromide, as well as many others, some of which are indispensable for the existence of animal life.

Whereas in the open ocean, the salinity usually ranges between 34 and 36 parts per thousand by weight, there are enclosed seas such as the Baltic and the Black Sea where the proportion is considerably less—less than 20 parts per thousand. On the other hand, land-locked basins in warm latitudes—the Red Sea—may range as high as 40, partly on account of the absence of rivers but mainly because of the constant evaporation taking place throughout the year.

The central portion of the North Atlantic has a salinity well above the normal. This is due partly to the high evaporation near the equator and to its distance from land and rivers, but there is no doubt that a very prominent part is played by the atmospheric conditions prevailing; the line of lowest mean atmospheric pressure is at all seasons north of the equator and so the warm surface currents of the South Atlantic are persistently flowing in that direction, carrying with them water of high salinity and high temperature. The effect of the highly saline bottom current from the Mediterranean affects the water at greater depth and must have an indirect influence when this latter rises to the surface.

In regions of heavy rainfall such as the northern Indian Ocean, the western Pacific and the West China Sea are areas of low salinity, whilst the same state of affairs is a permanent feature of the sea in the vicinity of the rivers, especially the Niger, Amazon, Mississippi and the great rivers of Asia.

These differences in salinity, and temperature are responsible for the circulation in the general mass of oceanic waters and provide oxygenation so necessary for animal life in the abyssal regions. It should be pointed out that the waters which leave the surface in the high latitudes, owing to their low temperature, carry down a greater quantity of atmospheric gases than would waters of high temperature from nearer the equator.

Organisms living in the open oceans or in coastal districts far from the mouths of rivers are as a rule very susceptible to variation in salinity, whilst those comprising the faunas of estuaries are usually unaffected by such changes.

An excellent opportunity for studying the effects in detail is presented by the Baltic Sea, full advantage of which has been taken by German and Scandinavian workers. At the Kattegat, the salinity at the surface is but slightly less than that of the North Sea, in the Kiel Bight it is reduced to one half, off East Prussia the surface salinity is one fourth of the normal, whilst at the north of the Gulf of Bothnia the water is practically fresh. Throughout its length the surface water has a lower salt content than the lower layers. The salinity as a whole is gradually decreasing, but the rate is so slow as to be almost imperceptible over a number of years. The

influence upon the fauna as a whole is well represented in the table below, which may be regarded as typical:—

	Marine Fish.	F. W. Fish.	Ascidians.	Lamellibr.	Decapods.	Amphipods.
Kattegat ..	(no data)	—	20	88	55	113
Kiel ..	75	—	5	23	9	18
E. Prussia..	40	6	—	6	2	11
N. of G. of Bothnia ..	23	20	—	4	—	5

In general the fishes attain a smaller size, the body is stouter, whilst spines and other external features are less developed. Reduction in size is also recorded for the Mussel, *Mytilus edulis*, the Cockle, *Cardium edule,* and the Jellyfish, *Aurelia aurita.* On the whole the Baltic is a shallow sea with a mean depth of 40 fathoms, having here and there both deeps and shallows. In the deepest of these the salinity is as high as 12% and yet the fauna is extremely poor, consisting of a few stunted individuals. At 40 fathoms 17 species are present, at 75 *Harmothoe sarsi* and *Priapulus caudatus* alone have been found, whilst at 120 fathoms no life has yet been observed. Absence of an adequate supply of oxygen and a superabundance of carbon dioxide have been recorded and may be the principal causes of the paucity of animal life in these deeper zones.

For many years the Baltic and other European seas have been the subject of marine biological research and our knowledge of conditions in these waters is perhaps unsurpassed. It has been found that the distribution of forms is not only influenced by light, salinity, currents and so forth, but that the **nature of the bottom** also plays a very prominent part. This has been well illustrated by the results published by Petersen, whose report is accompanied by very suggestive diagrams illustrating the numbers and composition of the animal associations at various stations. Muddy, sandy, rocky, and weedy bottoms each have their respective faunas, and it is generally only along the margins that the associations of two types of environment commingle to any marked degree.

Certain animal communities, which are characteristic, exist under certain physical conditions, and where these remain constant over large areas the related community will be found throughout. Thus the animals inhabiting the muddy bottoms in the belt of variables will have restricted ranges confined to such areas, but the community existing on the mud belt of the continental slope will extend much further, because this mud is more extensive and the other factors, light, temperature, salinity, etc., more uniform. **Depth** seems to have been but of little importance.

Changes in the physical environment bring about corresponding changes in the inhabitants, though it must be remembered that certain organisms may be found to be present in more than one community.

Another Factor is the **Conditions of the Water.** The presence of fine particles of mud in the water is a controlling factor in the case of many organisms. Corals cannot thrive under such conditions and, in general, geological evidence points to the fact that muddy water has in the past also been unfavourable for the existence of many forms of animal life. Though individuals may be numerous the fauna is poorer in species than the adjoining clearer parts of the ocean.

Among the benthos inhabiting such an environment to-day we find characteristic modifications among crustacea echinoderms and mollusca. Corals and sponges are rare and seem to avoid such surroundings as the individuals are often stunted and misshapen.

To-day clear water may often cover areas where mud is being deposited by the lower layers, hence the pelagic graptolites and cephalopods found entombed in mudstones, clays and shales may have found conditions suitable in the clear surface water and so may not necessarily have drifted in from other regions.

It must not be overlooked that muddy water is usually poor in oxygen content and therefore less capable of sustaining an abundant fauna.

The distribution and dispersal of the benthos, and particularly of the sedentary forms, are mainly the result of the powers of locomotion possessed by larval stages, or, if planktonic, of the strength and direction of the currents which may enable the organism to travel from one suitable site to another. It must, however, be recognised that many creatures possessing but limited powers are able to cover extraordinary distances. A few years ago a number of tagged crabs were liberated off the Northumberland coast, some of which were later captured. To reach the place where it was recovered one specimen must have travelled a mile a day, even if it moved consistently in the same direction, whilst another was captured 155 miles away, nearly two years after it had been given its freedom.

It would therefore seem possible for the majority of the organisms constituting the fauna of any one type of deposit occurring in the belt of variables to extend its range along the coast or across the shallows, provided the various limiting factors of the physical environment do not come into operation.

In order to be able to spread, however, the animal has to contend with difficulties of another kind, it has to be assured of an adequate and suitable food supply, and, what is often overlooked in discussions on dispersal, the creature has to find at every stage of its journey an environmental niche where conditions are such that it is able to exist for a longer or shorter period, until the process of dispersal can be continued.

In the case of an expanding organism, this extension laterally may be caused by pressure from the centre or by the attraction exerted by a favourable environment at the periphery. In any case the rate of progress will probably be slow and may be entirely suspended as conditions change unless some mutation, of which a variety tend to appear spasmodically throughout the animal's range, gives rise to individuals better fitted for life in the new surroundings.

If this occurs the new form may flourish and gradually replace the parent in that part of the periphery. On the other hand, if the novice is inferior to the parent it either fails to develop or is gradually crushed and eliminated in the bitter struggle for existence. As Willis very pertinently remarks, "Individual forms may owe their origin to many causes, but in most cases it would seem to have been due (immediately) to a mutation small or large which differentiated the new form from its predecessor, but there seems no reason to suppose that the new form is necessarily better adapted than its predecessor." Natural selection comes in, not as a causative and positive agent, but as a destructive and negative one.

To the biologist, who has to work in one plane—the present—this is more or less theoretical, but to the palaeontologist, who in favourable conditions can study the changes brought about in space (lateral dispersal) and time (evolution), it presents an interesting line of research, for it enables him to study the two interesting problems presented by what have been termed **Lineages and Convergence.** The palaeontologist, though hampered by the fact that his material consists almost entirely of the hard parts of organisms, which give him little information about the structure of the animal itself, has this advantage over the biologist that, now and again under favourable condidtions, the sedimentary rocks may enable him to study the evolution of a species or even a fauna over a period of time that must be reckoned in thousands or perhaps tens of thousands of years, according to the vertical extent of the exposures available to him.

In the case of certain fossils the development has been followed through thousands of feet of strata, the descendant being very different from the distant ancestor with which it is connected by a number of intermediate forms (transients) that merge into one another so that boundary lines are very difficult to determine, and can only be theoretical. In others, as for instance the graptolites, it has been shown that the general trend has been in the direction of simplification of certain structures until at the close of the series the descendants of several different types are, for convenience, united under the generic name of *Monograptus.*

Evolutionary changes of a different kind, but working along definite trend lines, have been revealed by a careful study of the Ostreas in certain beds of the Mesozoic in England. It would seem that capacity to vary along certain lines has been inherent in the oyster, at any rate, since early in the Jurassic, and when the necessary stimulus has been applied, either by some internal condition or by a change in the environment the new form has arisen and developed until it reached the end of its course, which generally resulted in extinction. Thus *Gryphaea, Alectryonia,* and *Exogyra* have repeatedly evolved from the original stock. Speaking generally *Gryphaea* is commonest in the Lias and Oolite, *Alectryonia* in the Oolite and Cretaceous, and *Exogyra* in the Cretaceous.

A LINEAGE IN CORALS.

Carruthers in 1910 published the result of his study of the evolution of a small zaphrentid coral belonging to a genus or species group common in the Lower Carboniferous of Scotland. The total thickness of the rocks examined is 5,000 feet, and hundreds of specimens were collected. Such a thickness of material represents the passage of a considerable period of time equivalent to thousands of years, whilst the large series from the various horizons enabled the worker to determine the composition of the community at these particular stages in its history.

In the Cement-Stone group 400 feet below the Fells Sandstone the form *Zaphrentis delanouei* was dominant, being accompanied by a few individuals of a form known as *parallela.* In the Lower Limestone group, some 2,000 feet above this horizon, *delanouei* has become rare, *parallela* is but a little more abundant, whilst a new form *constricta* is in the majority with *disjuncta,* which has evolved from it. Higher up in the sequence, the Upper Limestone group, *delanouei* is absent, *parallela* extremely rare, and *constricta,*

whilst by no means uncommon, quite subordinate to *disjuncta*, now the dominant form.

The points of difference between *delanouei* and *disjuncta* are such that they would be regarded as separate species were it not that the accidents of preservation and collection revealed the intervening transient forms linking the one with the other.

THE PROBLEM OF DESCENT IN GRAPTOLITES.

In dealing with the Graptolite faunas of the British Isles, Dr. Gertrude L. Elles remarks that these organisms, which were planktonic or pseudoplanktonic in habit, are usually found in shales or mudstones deposited in the deeper water of the Palaezoic seas where they are represented by carbonaceous films on the bedding planes. "When the history of the Graptotites is traced from their origin in the Tremadocian to their final extinction in the Upper Silurian, certain definite trends can be recognised; that is to say, through all the diversity of form, development takes place in relatively few and clearly defined directions in the many different lineages. Within comparatively narrow limits, this evolution takes place at comparable rate in all the different lines of descent, with the result that the whole aspect of the graptolite fauna changes as we pass upwards in time. On this basis, four graptolite faunas, dichograptid, leptograptid, diplograptid, and monograptid, have been described (Elles, 1922), and within each of these further subdivisions are possible on general evolutionary principles. At the same time, most, if not all, of the genera are polyphyletic and represent grades or stages of evolution rather than genetic relationship.

These Homoeomorphs are met with quite frequently, the patelliform gastropods offering an excellent example. In the Palaeozoic *Helcionella*, *Metopoma*, and *Pileopsis* represent three distinct eruptions of this trend, whilst later periods give us *Ancylus*, *Patella*, *Fissurella*, *Capulus*, and *Siphonaria*. In each case the impetus is in the same direction, and the ultimate result is extinction.

EVOLUTIONARY TRENDS IN OSTREA.

The genus *Ostrea* is a mollusc whose history extends back to the Upper Palaeozoic; though it does not come into prominence until Jurassic times, it was general throughout the Mesozoic and Caniozoic and is plentiful in modern seas. In the course of its long existence modifications along certain lines often appear; these may be in the direction of—(1) a thickened shell, (2) a curling in the umbonal plane, (3) a curling laterally, and (4) the development of ribbing. These features may develop singly or in groups. The thickening may often be observed in *Ostrea* (s.str); thickening and folding of type (2) in *Gryphaea;* a combination of (2) and (3) produces *Exogyra*, of which some species show an indication of (4). Lateral curling (3) and ribbing **(4)** are characteristic of *Alectryonia*.

A careful examination of the material available has led to the conclusion that *Ostrea* is an extremely virile and plastic genus with a tendency to variation in the form of the shell. Evidence which has been regarded as conclusive shows that the Gryphaeas, Exogyras and Alectryonias of later horizons instead of being the descendants of earlier forms have really sprung at intervals from the mother genus *Ostrea*. That is to say that these three "genera" are polyphyletic in origin. In the course of an investigation of the littoral

Lias of South Wales and Somerset, Dr. A. E. Trueman was led to submit the Ostreas and Gryphaeas to a close and critical examination as they were often the only fossils available for correlating the beds. He found the fossils present in satisfactory numbers and in places was able to trace the change from the flat oysters of the Planorbis zone to the completely incurved *Gryphaea incurva* in the Upper Bucklandi. In Glamorganshire where these zones of the Lias are most thickly developed and continuously exposed, the changes were completed whilst sediments representing 300 feet of the strata were being laid down.

It was found that the five "species" *Ostrea liassica, Ostrea irregularis, Gryphaea dumortieri, Gryphaea obliquata,* and *Gryphaea incurva* were members of a lineage and not separable one from the other. At every stage other variations occur, but the general evolution seems to be along the trend-line represented by these five "species."

In *O. liassica* the left valve is cemented to its support by the whole, or nearly the whole surface as in the *O. edulis* of Europe. The next form *O. irregularis* in its early stage resembles its predecessor, but as the animal grows the shell curls away from the support so that in the adult the attachment is equal to about half the total length. In *G. dumortieri* the curvature is much increased and the base of attachment is reduced to 30 per cent. of the total length. The next gryphaeate stage *G. obliquata* has it reduced to 10 per cent., whilst in the final stage of *G. incurva* the curvature has reached its maximum and the point of attachment is reduced to 4 per cent. of the length or may even be entirely wanting. The flat oyster *O. liassica* is most abundant in the "Oyster Bed" at the base of the Lias and extends upwards into the Planorbis and Caloceras sub-zones. The next phase, *O. irregularis,* is characteristic of the Liasicus and is very common in the Angulata sub-zone. *G. mortieri* occurs in the Angulata sub-zone of Glamorgan and Radstock (Somerset). The name *G. obliquta* has, according to Trueman, been applied to many gryphaeate forms from various horizons in the Lias, but the holotype is from the Blue Lias near St. Donat's Castle in Glamorganshire where the species occurs in the Vermiceras or Rotator sub-zone (Lower Bucklandi).

The holotype of *G. incurva* is from the Bucklandi zone at Fretherne, Gloucestershire, and an examination of an extensive series of this species shows that when it is one twenty-fifth grown it resembles *G. obliquata* one-tenth grown, or *G. dumortieri* one-third grown, or *O. irregularis* three-fifths grown, or an adult *O. liassica.* In other words, in the course of its development the species recapitulates the stages of its evolution from the flat oyster type *O. liassica.* Trueman found that whilst *O. irregularis* was still plentiful the form *G. dumortieri* had already made its appearance; before this had reached its prime *G. obliquata* was already in existence, to be followed shortly after by *G. incurva.* Plotting of the results obtained after an examination of hundreds of specimens showed that the new forms arrived with increasing speed and terminated with *G. incurva* because in the extreme type the coiling was developed to such an extent that it pressed against the opercular valve, prevented the shell from opening and thus brought about the death of the individual.

In a later paper the same author remarks:—"The difficulty of recognising distinct species within such a lineage will be apparent. If the lineage is incompletely known, owing to gaps in the geological record, the species may correspond to some natural and homogeneous group, but if the con-

ception of lineage put forward here—that it is a plexus of anastomosing lines, rather than a single line, or bundle of such lines—represents a correct view of the facts, in such cases it is clearly impossible to distinguish species.

In his first paper the author remarked that other Gryphaeas such as *G. cymbium* and *G. maccullochi* were probably also evolved from Oysters. Indeed it is extremely likely that these gryphaeiform shells have been repeatedly evolved during the Jurassic and Cretaceous from species of Ostrea that are similar and closely related, thus confirming the opinion expressed by Kitchin in the section on Palaeontological work in the "Summary of Progress of the Geological Survey of Great Britain for 1911" (1912). "It is evident that in the Lower Lias alone there are two or three separate derivations for such forms. The evolution of analogous gryphaeate stages was repeated in other stocks in various Jurassic and Cretaceous horizons. These stages seem never to have had a place in any main line of evolution, but to have arisen rapidly and to have characterised short-lived offshoots from ostrean radicals. Their study not only has great theoretical interest, by reason of the light it may help to throw on questions in which phylogenetic principles are involved; it must also lead to a better characterisation of the faunal assemblages in which gryphaeate oysters are found, and will have a corresponding practical value in zonal work."

The points that must be emphasised are that the change from *Ostrea* to *Gryphaea* has taken place repeatedly, the originating oysters being essentially similar, and the terminal gryphaeas somewhat alike. Also that the changes took place at *successive times* and in *different localities*.

The Gingin Chalk at Gingin and Dandarragan has already yielded a number of small ostreiform shells with large areas of attachment, which probably represent the young stages of *G. vesicularis*, and it is possible that when extensive collections are made at the mouth of the Murchison River, where the rock attains a thickness of 200 feet, it will be possible to indicate similar relations between *Ostrea* and *Gryphaea* in Western Australia.

Similar results have been obtained in other groups of organisms. Dr. Bather expressed the opinion that the plan of Pentacrinine stem on which the genus *Balanocrinus* was based has arisen from *Isocrinus* several times over during the Mesozoic and Cainozoic Eras, and apparently in various seas of the world.

Inoceramus of the Cretaceous, *Carbonicola* and *Anthracomya* of the Carboniferous have yielded almost complete lineages, the former flourishing in the Chalk Seas, the others living under conditions probably similar to those enjoyed by the Unios and Anodontas of to-day.

It has now been established that in any series examined there is considerable variation among individuals collected at one horizon, and this seems to be greatest in sedentary forms. At each horizon the variation appears to be continuous and the characters are on the whole independent.

These results do not agree with the accepted views in biological science, but the gap may be narrowed if not entirely bridged as our knowledge of the evolution of animals in past ages becomes more complete. It does, however, seem to be definitely established that these evolving series of stock are to be regarded as a plexus of anastomosing lineages and not as parallel lines of descent, for there must have been extensive interbreeding at all stages.

The amount of change varies enormously; in certain stable forms (*Lingula*) the changes have been remarkably slight in the hundreds of millions of years that separate the Lower Palaeozone from the present, in others (*Ostrea*) experiments along definite trend lines have been made repeatedly, though the main stem has managed to survive without marked specialisation from the Lower Jurassic to Recent times.

These facts may be regarded as a warning against hasty generalisation. Each genus, perhaps even each species, must be carefully studied in detail before the value of the evidence it has to offer can be correctly appraised.

The more we probe into Nature's secrets and the more her ways are disclosed to us, the more we are inclined to join with the great Linneas in his wonder and admiration, and the more eager we are to echo the sentiments expressed so ably on the title page of his great "Systema" published nearly two centuries ago—

O. Jehova!
Quam ampla sunt Tua opera!
Quam sapienter Ea fecisti!
Quam plena est Terra possessione Tua!

POWERS OF DISPERSAL POSSESSED BY VARIOUS GROUPS OF MARINE ORGANISMS.

FORAMINIFERA.

Most of the members of this important group of simple organisms are marine, the greater number move along the sea bottom, but some forms are pelagic, whilst *Globigerina* and *Orbulina* live at the surface. A few are encrusting, and to these Professor S. J. Hickson would add the Stromatoporoids.

Owing to their mode of life the lateral dispersal of most species would depend upon the slow movement of ocean waters; the pelagic species on the other hand might be spread by surface currents and movements resulting from tides and the action of the wind. Many of the simpler forms have changed but little during the passage of vast periods of time, only the more complex being of value in closer correlation.

Much of the so-called variation in the Foraminifera may be divided into groups. The first of these may be those due to the different stages in the development of the organism. The second class are due to the two distinct forms—sexual and asexual. The third class show true variations, that is, actual size in adults, variations in ornamentations in the adult, and other like characters. A study of Foraminifera from an area of such as that of the Western Atlantic from Newfoundland to Brazil shows that many faunas in the region have very definite limits, bathymetrically and geographically. Some are very restricted, others are more widespread, exactly as in other groups of the animal kingdom.

When intensive collections from widely separated localities as Samoa, the Philippines, New Zealand, and Hawaii are studied the differences are very marked, though all comprise one great geographical fauna.

PORIFERA.

Sponges are either sessile or encrusting, and, therefore, their distribution is determined by the length of the free swimming larval stage and the power of locomotion possessed by the young organism. Both of these factors are very limited in their scope, consequently dispersal must be a very slow process, even if environmental conditions are favourable. At times sponges become attached to living organisms, such as seaweed crabs and sponge crabs, when the activity of the crustacean must be considered.

Fragments of sponge become detached in stormy conditions, and may under certain circumstances be carried some distance by ocean currents and left in an environment in which the organism is able to establish itself successfully. Reproduction by budding is affected by similar controlling factors.

Reproduction by gemmulation is a feature of fresh water sponges found also in certain marine forms; as the gemmule is entirely dependent upon external conditions for its dispersal, it need not be considered in greater detail. It must, however, be noted that this structure is extremely hardy, and may persist for some time in an unfavourable environment without suffering deterioration. All the larger groups of sponges are cosmopolitan in their range, but this does not apply to genera and species, which are confined to definite geographical areas.

As regards their distribution in depth, the Calcarea and the Ceratosa are strictly shallow-water forms, the Monaxonida and Tetractinellida prefer depths from 51 to 200 fathoms, whilst the Hexactinellida are characteristic of deep water. In the main it is true that sponges occur generally in the vicinity of land, and this applies to the deep water as well as to the shallow water species. The deep ocean forms an efficient barrier, except when it is studded with islands which provide suitable depths and favourable bottoms. Miss Sollas considers that "six days is not an excessive interval to allow for the larval period of at least some species."

COELENTERATA.

Although corals range from the tropical seas to temperate waters the massive reef-building forms are confined to areas where the temperature is not less than 21 degrees C, and the annual range not more than 7 degrees C. The southern limits of coral reefs in the Australian region are the Abrolhos Islands, on the west, and Lord Howe Island, on the east.

Reproduction may be by fission, gemmation, or fertilised ova. Under ordinary condition the first two methods do not lead to migrations of any moment, whilst in the case of the third, the possibilities are also somewhat limited. According to Duerden most Madreporaria are viviparous, the ciliated larvae swimming about for a day or two, and then settling down. On the other hand many forms have brood pouches in which the larva remains until it has reached a stage with twelve or more tentacles.

In his "Coral and Atolls," Professor F. Wood Jones devotes a chapter to the corals and the coral problem, and, after describing a reef and the coral zooids, deals with the early stages of the larvae. He concludes: "Although it has been said that the larvae becomes fixed after a few days passed as an active, free swimming creature, still, among those that have been watched in aquaria

a great majority display a singular reluctance to settling down; among Wilson's larvae of Maniciana many did not settle down till they had spent three weeks swimming free, and Duerden came to the conclusion that if fixation did not take place within the first few days, it did not occur at all, although the larvae continued to swim slowly about the vessel, and even rested temporarily on their sides. These wandering larvae, though they lived for several weeks, undergo no development. They never attain tentacles, they acquire no skeleton, and yet, if fixation does at length occur, it provides the necessary stimulus and growth and development proceed vigorously even under unfavourable circumstances. A larva may in this period of non-development be carried far by currents, and it is evidently an important factor in the economy of corals that this stage of developmental activity should last long in some members of the brood, for thus the chances of the spread of a species become greatly increased."

The observations made by the recent Cambridge Great Barrier Reef Expedition do not seem to support the conclusions arrived at by Professor Wood Jones, but would seem to support the view of Professor J. S. Gardiner that the larvae lived for seven or eight days. No planulae were found by the latter more than 50 miles from the shore, so that, for instance, the larvae could not possibly reach the Maldives from Ceylon by a direct route.

STROMATOPOROIDEA.

As already pointed out these organisms are of doubtful affinity; there is a tendency to-day to regard them as encrusting Foraminifera following the view expressed by Carpenter and not as relatives of the Hydroidea which would accordingly be confined to the later Cainozoic.

BRACHIOPODA.

The few and scattered remnants of the once prolific brachiopod fauna, on account of the specialisation which has undoubtedly occurred in certain forms, can give us but an imperfect picture of the means of dispersal available to their ancestors of Palaeozoic times.

Some genera, as for instance, *Lingula*, seem to have changed but little in the millions of years that have passed since the Proterozoic. Then, as now, they preferred a muddy bottom in shallow water, and we may assume that in the Silurian seas their migrations were performed during the free larval stage which probably did not exceed a month in duration. Sewell reports the capture of larvae in tow nets operating in waters about four miles off the South Burma coast and even if this distance is exceeded we can appreciate the difficulties that face the larvae in their efforts to discover suitable environments and the length of time necessary for one of these species to extend its range by a thousand miles.

In *Discina* the larval free swimming period is shorter than that of *Lingula*. In the case of *Terebratulina* the eggs pass out of the shell of the mother and hang in clusters on her setae and surrounding objects. In a few hours the larvae become ciliated and swim about freely for a period that may extend to 10 or 12 days, though generally much shorter; as the species usually occur in isolated closely populated colonies of considerable age in terms of years. Such brachiopod colonies are characteristic features in many lime-

stones, and are familiar to all who have made collections of Silurian, Devonian, Carboniferous and Jurassic species, in suitable localities. It is this peculiarity which influences certain well known authorities to disregard brachiopods as unsuitable zone fossils.

In *Cistella* according to Shipley the free larva is very minute and spends but a short time in the motile condition, and this probably accounts for the fact that Brachiopods are extremely localised. When they do occur they are found in great numbers, rocks being sometimes almost covered with them. It is doubtful whether the larvae swim a yard an hour. After swimming for a few hours the larva fixes itself and once having settled down the animal never moves from the site selected. In *Thecidium, Cistella,* and *Argiope* the first stage of development up to the completion of the larva takes place in brood pouches (Shipley), whilst in *Lacazella* the free swimming stage is entirely suppressed (Thomson). Thomson summarises the position as follows:— "From these facts Blochmann concludes that the power of distribution is very limited, and that the larvae are unable to cross the oceans from one coast to another. Only a few species live in depths of over 2,000 metres (roughly 1,000 fathoms) and a gradual migration across the deep oceans along the bottom is impossible for other species. The majority of brachiopods are found in the submarine slopes of the continents and neighbouring islands and the deep oceans are barriers which they cannot cross. Cases of discontinuous distribution of the shallower water forms have therefore a profound significance, and permit conclusions as to former land connection to be drawn.

"Before these conclusions can be regarded as definitely established, however, more must be learnt of the structure of the larvae and of the duration of the free swimming stage in a larger and more varied series of genera."

In view of the above, S. S. Buckman's view that certain species of brachiopoda have been spread evenly over vast areas at the same time (hemera) of which they are characteristic seems untenable.

ECHINODERMATA.

Among the Echinoderms of to-day we find two types of development, the "embryonic" and the "larval." In the former, which seems to be confined to warmer waters, the parent in nearly every observed case carries the young about with her until they reach the adult form. In the larval type the egg contains very little yolk and the larva is soon forced to seek its own food; in the blastula or first well-marked larval stage the organism rises to the surface plankton. This may occur in from 12 to 24 hours after fertilisation; later in from 20 to 36 hours the gastrula stage is reached. Further changes produce the Dipleurula larva, each class of the phylum having its characteristic type. The period spent in this free swimming condition ranges from two weeks to two months, after which the metamorphosis to the adult form takes place and the normal mode of life is adopted.

With the exception of the Crinoidea, which contain forms able to swim actively with a lashing movement of the feathered arms, the Echinoderms as a whole have but limited powers of locomotion in the adult state. Chances of dispersal thus seem to be confined to the period that the larva is a member of the plankton and is governed by the condition of the environment when the mature form is adopted. If no suitable site is found the organism soon dies. Fossil evidence suggests that echinoderms were

either rare or entirely absent in muddy seas with a low lime content. According to Mortensen, Echinoderm larva are rare in high sea plankton.

MOLLUSCA.

We may assume that pelagic forms comprising Pteropods, Heteropods as well as certain Cephalopods and Gastropods (*Ianthina,* etc.), were capable of wide distribution in the past as much satisfactory evidence is provided by the living examples of modern seas where they are found among the plankton. When, however, we consider forms which as adults inhabit the sea bottom or the shore we find that the movements of the ocean waters in which the free swimming larval stages form a part of the plankton are practically the sole means of dispersal. In the adult form *Cardium* and *Trigonia* may jump with the help of their flexed foot; rapid opening and closing of the shell is adopted by the Scallops (*Pecten* s.l.), whilst most Gastropods are able to creep over the sea bottom or along vegetation. After storms they may occasionally be found on floating seaweeds and cuttlebones. Food supply, especially for the phytophagous species, and temperature are important factors. According to Dr. Dudley Stamp "Deuville has shown that the distribution of *Rudistes* was determined by warm currents." To-day Gastropods are more abundant and varied in depth of less than 50 fathoms than in deeper water, the vegetable feeders cannot exist below the sea-weed zone, and of the carnivorous species only a few stragglers are reported from the abyssal region.

Among the Cephalopoda, the highest of the Mollusca, both the Dibranchia and the Tetrabranchia include pelagic forms which on account of their powers of locomotion are widely distributed in the oceans of to-day. Some abound on the continental shelf, others are truly pelagic, whilst others again are members of the abyssal fauna and thus have an extremely wide range. Many cuttlefishes prey upon fishes, which they pursue with vigour; the octopus prefers a rocky environment where, from its lair, it attacks passing organisms with its long arms. *Nautilus,* which has been observed crawling along the sea-bottom, can also swim by expelling water through the funnel. It is believed that the fossil Belemnites had similar locomotive powers.

Little is known about the life history of the Ammonites; their lateral distribution is generally more extensive than that of other Mollusca, which would suggest that they had more efficient means of dispersal and were less susceptible to changes of temperature and other external factors.

It is assumed that during the very early stages the organism was a member of the plankton and so at the mercy of winds and currents. Later the shell developed and then, it is thought, most of the forms went to the bottom where they probably lived very much as the recent *Nautilus,* by crawling along the bottom, though able to swim actively in the shallow seas which they inhabited.

Spath considers that the Lytoceratids and Phylloceratids were probably pelagic, preferring to live in warm surface waters and currents, and thus able to reach Dorset and Yorkshire in England from their home in the Mediterranean region. At the same time he would stress the fact that as a rule Ammonite zones are not universal; in fact, of the 553 species dealt

with in "The Jurassic Caphalopoda of Kachh (Cutch)," no less than 400 are local. "Faunal identity in different areas." he concludes, "may indicate anything but contemporaneity."

CRUSTACEA.

This phylum is usually well represented in the plankton; Copepoda, Cladocera and Ostracoda are nearly always present, whilst areas often show rich seasonal developments of Mysidacea, Amphipoda, and Euphausiacea. In addition, the neritic plankton contains the larvae of the coastal and shallow water benthos which may under favourable conditions also be found in the plankton of the high seas. Prof. J. Stanley Gardiner has even stated that there is no bank to which the crustacean larvae cannot get. Many of the more active species have a very wide range; the edible swimming crab is found over a large portion of the Indo-Pacific, due to its powers in both larval and adult stages; the more or less sedentary Stomatopoda owe their wide range to the long life and activity of the larval stage. *Gonodactylus charagia* is known over a vast area in the warmer regions and has often been found alive in British seas, although the temperature of the water there does not allow the species to become established.

The little Gulf Weed Crab, *Planes minutus*, so often found on our ocean beaches after storms, is a traveller of another class, for its dispersal is of a passive nature, the animal travelling with the mass of sea-weed upon which it is living. Like the Nudibranch *Glaucus* and certain Gastropods, it has been found upon cuttle bones coming in from the sea.

Another member of the pseudoplankton is the Barnacle. The young of this crustacean hatch into free swimming nauplii which in from 1 to 10 days metamorphose into bivalved cyprid larvae. It spite of the short duration of the free state many species are almost world wide in their distribution; this is perhaps mainly due to the fact that the larva may attach itself to floating objects. It is stated that temperature of the water is a limiting factor in some species.

Other members of the pseudoplankton are the Whale-lice, Cyamidae, infesting certain Cetaceans, Hyperidea which have been found associated with Jellyfish. Among the benthos Caprellids have been found on Starfish and Gammarids or Spider Crabs. Parasitic Crustaceans (Copepoda, Cirripedea, Isopoda, etc.) attack other crustaceans and fishes and so become dispersed through the activities of their hosts.

PISCES.

Marine fishes may be divided into two groups, those inhabiting the open ocean and those found only in shallow seas and along the coasts. The former, if not confined to the upper waters, find every opportunity of enjoying a wide world-range; the slight variation in temperature, salinity and light form no barriers, and the food supply, consisting of other animals or of bodies of organisms falling from above, provides little variation. In the upper layers down to 150 fathoms are found the large predaceous Sword-fish, the Tunny, and their kin, as well as hosts of smaller forms. Some of the latter feed upon the plankton, others prey upon smaller fishes, and often make long migrations when following their normal food supply in its seasonal progress.

Coastal fishes, on the other hand, are more limited in their range, the most important limiting factor being the temperature of the water. As the temperature belts run roughly east and west, and the coastline generally trends north and south, the latter is divided into a number of regions, each containing a number of characteristic forms which are usually unable to mingle with those of a similar environment elsewhere.* The tropical zone contains by far the greatest number of genera and species, but the forms inhabiting the colder waters far surpass their fellows of the tropics in the numbers of individuals belonging to any single species. This peculiarity is not confined to fishes, for it has been observed in many other groups of marine organisms, so that we are permitted to assume that it is an ancient feature which has survived from the earliest geological times when life on the earth was still young.

In its early larval stages the tiny fish is at the mercy of the currents, and must be regarded as a component of the plankton of the open sea or coastal shallows.

At a later stage power of movement is increased, and then the young fish passes to the nekton. The distribution of coastal fishes, particularly those preferring the shallows, provides some interesting evidence concerning the former distribution of land and sea, particularly in Caniozoic and later times.

* Conditions must have been very different in the days of the Tethys sea when temperature belts and coast lines were more or less parallel to one another.

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1.—THE GEOLOGY AND PHYSIOGRAPHY OF THE JIMPERDING AREA

by

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CONTENTS.

I.—INTRODUCTION. *

The Jimperding Area, situated about 50 miles North-East of Perth by road, is typical of the country forming the Northern parts of the Darling Range. Nearer Perth the areas as previously mapped in detail (Clarke & Williams, 1926 ; Fletcher & Hobson, 1931) consist almost entirely of granitic rocks with later basic intrusions, whereas North of the junction of the Chittering Brook with the Swan River, the country rock changes to ancient metamorphics which appear to be older than the granites forming the Southern parts of the Range.

Attention was first drawn to this area by Mr. J. E. Wells, who, in 1927, noticed the occurrence of andalusite schist in the district. Detailed geological mapping of the area was commenced in 1928, but most of the work was done during 1931 by parties of senior students and the author, working under the leadership of Professor E. de C. Clarke.

The area (which covers approximately $8\frac{1}{2}$ square miles) has been subdivided by the Lands Survey Department, thus obviating the necessity for detailed preliminary survey work. Geological and topographical details were done mainly by chain and compass traverses of the creeks and ridges, while the intervening spaces were filled in by pacing. Levelling, sufficiently accurate for the drawing of form lines, was done by aneroid barometers, using the Jimperding Hill Trig Station as datum. The heights of various points were established by frequent checkings on the Trig station, and intermediate heights were taken from those thus established.

Early in 1931 this locality attracted some attention owing to the discovery of a little alluvial gold in Yinnerding Creek in the Southern part of the area, but a discussion of this occurrence will be deferred to a later part of this paper.

II.—PHYSIOGRAPHY,

A.—General Relief :

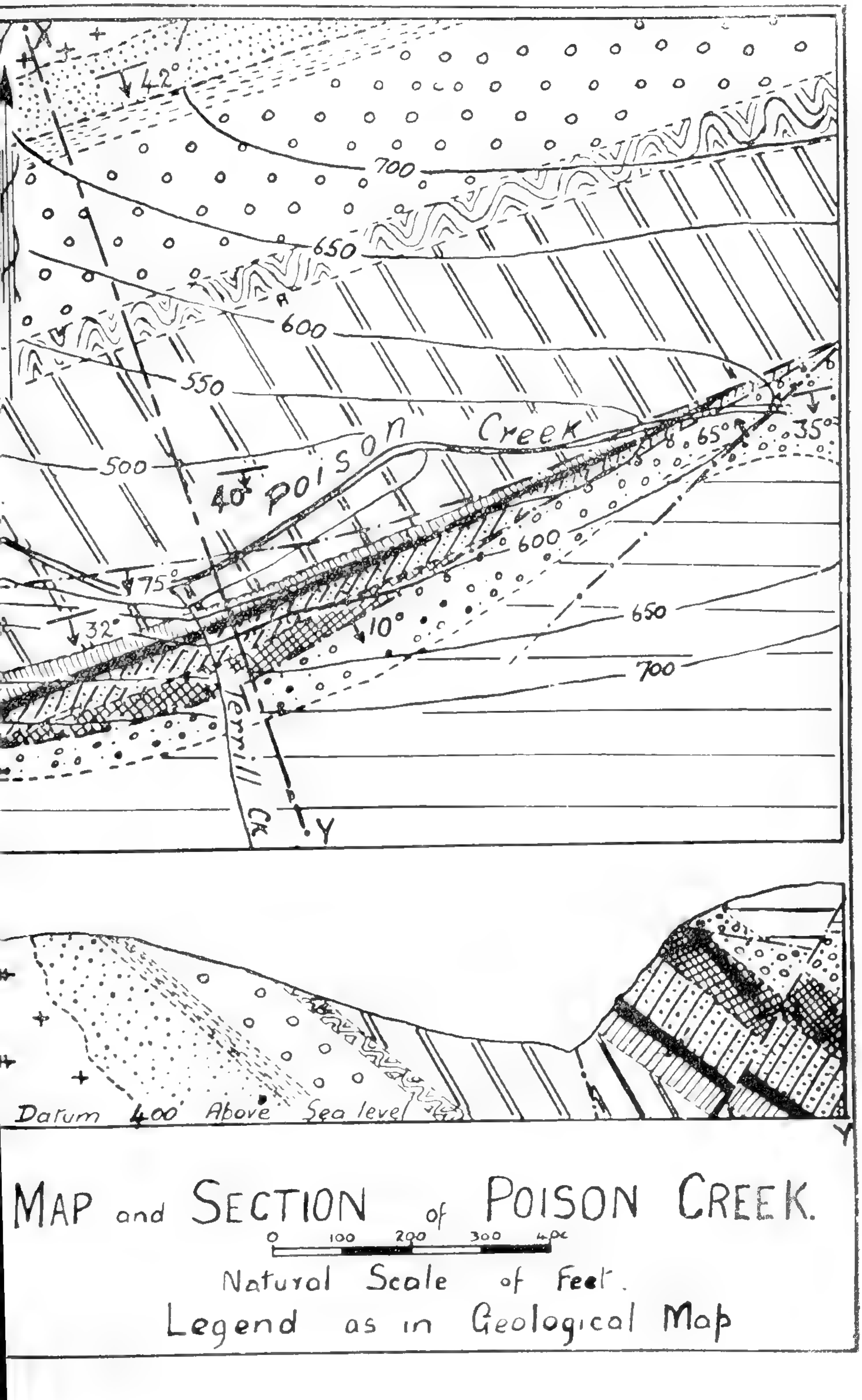
Topographically the area can be divided into two sections—(1) a Northern section lying to the North and East of the Jimperding Brook, and consisting of immaturely dissected high land ; (2) a Southern section of maturely dissected country rising gradually to the level of the Darling Peneplain.

The map accompanying this paper clearly indicates that the area is portion of an old tableland. Dissection by Jimperding Brook and its numerous tributaries has produced the present topography.

B.—The Avon River and Its Tributaries :

The Avon River, which flows from East to West along the Northern boundary of the area, is a mature stream flowing in a wide V-shaped valley incised in the old Darling Peneplain. In this area it has two main left bank tributaries—Jimperding Brook and Poison Creek—streams which have several common characteristics, but differ greatly in stage of development. These two streams flow parallel throughout their course, being separated by a ridge of gneissic rock which extends East and West at a general height of 900ft. to 950ft. above sea level.

* Part of the cost of this publication has been borne by the Department of Geology, University of W.A., and by the Author.



MAP and SECTION of POISON CREEK.

Jimperding Brook, which flows in a general Westerly direction throughout the greater part of its course, changes its direction in the centre of the area and flows North, entering the Avon Area near the Northern boundary of the Jimperding area. Jimperding Brook is an intermittent stream which flows rapidly during the winter months, but is reduced to a few disconnected pools during the summer. It is a mature stream flowing over a flood plain about 5 chains wide, in which it has incised a meandering course. The valley is unsymmetrical, the land rising more steeply to the North than to the South, a fact which may be explained by the presence of softer schists to the South and harder and more resistant gneiss to the North.

The tributaries of the Jimperding Brook are small streams which flow only after heavy rains. The general trend is in a Northerly direction, having probably been influenced by major jointing in the rocks. The tributaries are divisible into two main types :—

(a) Those which enter from the Northern side of the Brook, draining the North-Eastern block. These tributaries are mostly short, and all have a steep grade with frequent falls in their course.

(b) Those flowing in from the South and South-West have lower grades, few waterfalls, and are generally of greater length than those of type (a).

The most noticeable feature in the course of Jimperding Brook is the right-angled bend where it changes direction from a Westerly flowing to a Northerly flowing stream. It appears to follow the strike of the rocks which swings round to a Northerly direction in this part of the area. Apart from the fact that the stream is influenced by the strike of the rocks, I have been unable to account for this remarkable change in the course of the stream.

The tributaries, Wonderling Creek, Yinnerding Creek, and Hillsdale Creek, are separated by flattened spurs which show evidence of high level terraces at about 600ft. above sea level.

The North-Eastern section of the area is drained by Poison Creek, a tributary of the Avon River. This stream, which flows parallel to Jimperding Brook, is of juvenile character, having a steep grade with numerous waterfalls in its course. It is intermittent in flow. Although this creek flows only after heavy rains, it is actively degrading its course, and thus differs markedly from the Jimperding Brook, which has nearly reached grade.

The course of Poison Creek appears to have been determined mainly by faulting, and the contrast with Jimperding Brook may be due mainly to this, and to the fact that the Brook flows through a region of softer rocks.

III.—GEOLOGY AND PETROLOGY.

A.—Structural Geology and Field Relations of the Rocks:

1. *The Rocks.*—The rocks exposed in the area under discussion are a series of metamorphics with later acid and basic igneous intrusives.

The metamorphics are a conformable series of quartzites, gneisses, and schists, which occupy the Northern half of the area. They strike West with a general Southerly dip seldom exceeding 20°. A study of the geological map shows that the various types of metamorphic rocks preserve an almost uniform thickness throughout the area. In the Southern part the country is granite with small isolated patches of mica schist. Although the actual

contact of the granite and metamorphics has not been found, the boundary is accurate within a chain or so, and clearly shows that the granite is an intrusive mass, and that the isolated patches are roof pendants.

The metamorphics and the granite have both been invaded by acid and basic dykes. The basic dykes have a general North to North-West trend. Some may be followed for a mile or so along their strikes, others can only be traced for a few chains. The basic dykes appear to be more numerous in the South-Western section, where they mostly have a uniform width of two or three chains. The field relations of the basic dykes suggest that they all belong to the one period of instrusion, for no intersecting dykes were found.

The quartz veins and acid dykes (pegmatite and muscovite-garnet-granite bars) have no uniform trend or size, and are usually traceable for short distances only. They appear, however, to be more numerous in the metamorphics situated close to the granite contact than in those farther North.

Later superficial deposits take the form of duricrust and alluvium. The duricrust is developed in the South-Western part of the area, mainly overlying the granitic rocks, but also occurs as residual knolls overlying the metamorphics in the North-Eastern section. Alluvium occurs on the flood plains of the Jimperding Brook and the Avon River.

2. *The Structure.*—The structure consists essentially of a series of conformable bands of crystalline schists, which have been tilted and gently folded. Earth movements have produced tilting mainly towards the South, with minor puckered folds distributed throughout the area. Where Jimperding Brook changes its direction from Westwards to Northwards, there is a distinct variation from the normal strike, and there is a small structural basin where the strike swings round towards the North, which probably accounts for the change in the course of the stream.

The folding in all parts of the area is of a gentle nature, and there has been little faulting in the main body of the metamorphics. In the Poison Creek section in the North-Eastern corner, fault breccia outcrops along the course of the creek, and the existence of a fault is corroborated by mapping. The fault strikes Westward with several branch faults, but owing to the presence of a thick mantle of quartzite rubble, no information regarding the dip or throw can be obtained.

In the Southern part of the area the granite appears to take the form of a bathylithic intrusion as evidenced by the irregular character of the outcrop, and the presence of inliers of mica schist belonging to the metamorphic series. The granite probably extends under the metamorphics, and may be represented by the granite outcrops found several miles to the North-West of the area, but no geological work has been done in this region.

The schists at the head of Beryl Creek and Yinnerding Creek, near the granite contact, are closely folded in a small way. The contortion and puckering seen here are distinct in character from the larger folds in the competent quartzite and gneiss bands farther North. These minor folds appear to result from the action of compressive forces in the incompetent mica schists and quartz mica schists near the granite contact.

B.—METAMORPHIC ROCKS:

The name "Jimperding Series" has been suggested (Clarke, 1930, p. 12) for the metamorphic rocks exposed in this area. They consist of interbedded quartzites, gneisses, basic schists, micaceous schists, and andalusite schists, attaining a total thickness of about 3,500ft., as exposed in the mapped area.

The succession and approximate thickness of the series is as follows, in descending order :—

Micaceous Schist—A. Ferruginous muscovite Schist ... B. Andalusite Schist ... ... C. Intercalated bands and lenses of Quartzite	250 feet at least.
Basic Schist and Gneiss—A. Tremolite Schist ... ... B. Actinolite Gneiss	300–350 feet.
No. 5 Quartzite	500 feet.
Upper Gneiss	1,800–1,900 feet.
No. 4 Quartzite	100 feet.
Basic Gneiss	75 ,,
Middle Gneiss	60 ,,
Hornblende Gneiss	10 ,,
Lower Gneiss	20 ,,
No. 3 Quartzite	150 ,,
Hornblende Gneiss	20 ,,
No. 2 Quartzite	100 ,,
Lower Mica Schist	20 ,,
No. 1 Quartzite	Thickness unknown.

The belt of metamorphics probably extends to the West into the valley of Chittering Brook, where it is represented by gneisses, and by kyanite schists, sillimanite schists, and staurolite schists. The Chittering metamorphics appear to have a Northerly strike, to be more steeply dipping, and to be much less regularly arranged than the Jimperding metamorphics. To the North-East the metamorphics are said to occur at Toodyay and Bolgart, with a further occurrence between Northam and Goomalling (Maitland, 1899, p. 28). From Jimperding they also extend South-East to Clackline, and probably farther towards York (Clarke, 1930, p. 13).

1. *Quartzites :*

Several very siliceous bands occur interbedded with the gneisses and schists. These rocks which have a bedded appearance in the field (Fig. 1) and banded appearance in hand specimen, have been termed quartzites. The definition of a quartzite (Hatch and Rastall, p. 298) as " a recrystallised

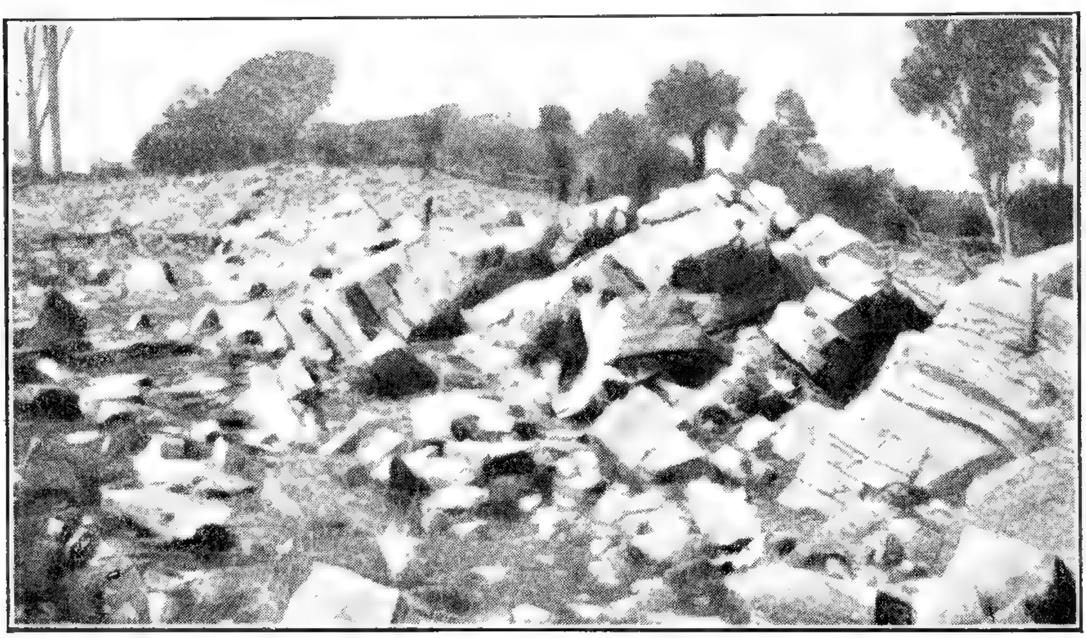


Fig. 1. Showing bedded appearance and mode of weathering of quartzite.

sandstone in which the original structures are destroyed, and the whole is converted to a mosaic of clear formless crystals of quartz without regular outline, but with closely interlocking crenulated edges " appears to be applicable in the present instance.

In the field, the various quartzites all weather into a flaggy rubble. In any of the quartzites one can generally find greenish mica flakes on the rock cleavage planes. This mica contains chromium and is therefore referred to fuchsite. Thus, the various members of the quartzites are indistinguishable in hand specimen. A marked difference, however, is noticeable in thin section. All have been totally re-crystallised, as evidenced by the complete absence of clastic and cataclastic structures such as interstitial cementing material, granulation, and strain shadows. The texture in all types is granoblastic allotriomorphic with a tendency to granoblastic gneissic in the lower bands.

The characteristics of the various bands are:—

No. 1 Quartzite.—Coarse grained, average grain size 1·8 mm. to 2·0 mm., consisting mainly of quartz with subordinate mica and felspar. The mica is developed in colourless flakes and slightly greenish laths about 0·4 mm. long, which frequently penetrate, but are never wholly in the quartz. The mica laths are frequently corroded and contain a yellow stain.

Felspar is clouded, allotriomorphic to subhedral, and is oligoclase.

No. 2 Quartzite.—The quartz grains averaging 1·5 mm. to 2·0 mm. in size contain as inclusions numerous small colourless mica rods about 0·015 mm. in length, which have their long axes more or less parallel. Greenish mica (fuchsite) is frequently moulded around the quartz grains. Felspar is rare, but where it does occur it is included in the quartz.

No. 3 Quartzite.—The most noticeable characteristic of this band is the grain size. The rock consists of bands of medium-grained granitic texture of average grain size about 0·8 mm. alternating with finer grained bands of gneissic texture of average grain size about 0·3 mm. The fine grained bands contain abundant felspar in irregular elongated allotriomorphs. In this type the felspar is not included in the quartz, and consists of two varieties, viz., microcline predominant, and a plagioclase which has not been indentified.

Apatite and rutile are found as accessories, but both are rare.

No. 4 Quartzite.—This type is more equigranular than the No. 3 band. It contains abundant free felspar (mostly microcline) occurring in subhedral to slightly rounded forms. Mica is an important mineral, and occurs in irregular colourless flakes frequently moulded on the felspar.

Apatite and zircon occur as accessories, but both are very rare.

No. 5 Quartzite.—The grain size and structures are very similar to those of the No. 4 band, except that felspar is very rare. The chief characteristic of this band is the presence of numerous minute rods of colourless mica, which occur included in the quartz. These inclusions are oriented in a parallel manner with striking uniformity (Fig. 2).

Fig. 2. Photo micrograph. No. 5 Quartzite showing micaceous inclusions in quartz. Crossed nicols x 40.

Photo. H. Smith.

This characteristic, and the fact that felspar does not occur except rarely as inclusions in this type, provide means for distinguishing quartzites of this band from the lower quartzitic members of the series.

2. *Acid Gneisses :*

The acid gneisses are represented by the Upper Gneiss, the Middle Gneiss, and the Lower Gneiss. The main band (the Upper Gneiss) attains a thickness of 1,800ft. to 1,900ft., and in this band numerous basic schlieren, consisting entirely of hornblende, are frequently present in the vicinity of basic dykes. The Middle and Lower Gneisses, which are more basic in composition than the Upper Gneiss, are separated from each other by a band of hornblende gneiss. A band of basic gneiss separates the Middle Gneiss from the No. 4 Quartzite. The total thickness of the four bands does not exceed 170ft.

The texture of all the acid gneisses is holocrystalline gneissic of variable grain. In thin section all the gneisses are granoblastic gneissic to porphyroblastic gneissic. All types have been extensively re-crystallised, as evidenced by the general absence of strain effects, and by the rather even grain in individual specimens. The chief mineral components are quartz, microcline, and plagioclase (all abundant) ; biotite (mostly chloritised) is abundant in some specimens. The accessories are apatite, epidote, iron ore, zircon, and rutile, the last two minerals occurring in a few sections only. Myrmekite is developed in most of the gneisses where plagioclase is in close proximity to microcline.

3. *Basic Schists and Hornblende Gneisses :*

The rocks of this group include hornblende gneisses, basic gneiss, actinolite gneiss, and tremolite schist. Bands of these rocks occur interbedded with the quartzites, schists, and acid gneisses.

The hornblende gneisses occurring near the bottom of the series are exposed in the North-Eastern section of the area. They consist of common blue-green hornblende, quartz, felspar (mainly labradorite), and accessory iron ores (frequently surrounded by a thin rim of sphene), epidote, and apatite.

The band of basic gneiss between the Middle Gneiss and the No. 4 Quartzite is composed of a fine-grained mosaic of quartz, saussuritised felspar, and hornblende, the hornblende being slightly elongated in the direction of gneissosity.

The actinolite gneiss and tremolite schist occur near the top of the series. The actinolite rock is much lighter in colour than the lower hornblende gneisses, and consists of actinolite, quartz, and felspar (mostly albite). The actinolite rock grades up into the overlying tremolite schist, which consists entirely of light green to colourless rod-like aggregates of tremolite.

4. *Mica Schists :*

Mica schists form the uppermost band of the Jimperding Series. They consist of two types :—

(a) Ferruginous muscovite schist.

(b) Ferruginous muscovite schists with andalusite.

The ferruginous muscovite schists consist chiefly of muscovite flakes (stained with reddish oxide) and anhedral quartz. The andalusites are developed in the portion of the mica schists that immediately overlies the

basic schists and attain an average size of $1\frac{1}{2}$ cm. x 1 cm. x 1 cm. These crystals become apparent on the weathering of the schist. Many of them show the characteristic chiastolite cross.

The andalusite, by retrogressive metamorphism (Knopf, 1931) is in some places altered in whole or part to an aggregate of muscovite flakes.

Another band of mica schist, similar to the ferruginous muscovite schists described above, occurs near the bottom of the Jimperding Series.

C. IGNEOUS INTRUSIVES:

All the igneous rocks of the Jimperding area are intrusive into the metamorphics of the Jimperding Series. They have been sub-divided as follows: -

(1) Granites and associated acid intrusives -
- (a) Normal granite.
- (b) Pegmatite, aplite, and garnet-muscovite-granite.
- (c) Quartz veins.

(2) Basic intrusives
- (a) Dolerites.
- (b) Epidiorites.

(1) *Granites and Associated Acid Intrusives:*

(a) *Normal Granite.*—The normal granite crops out in the Southern part of the Jimperding area, and also farther to the North-West along the Avon valley. Its relation to the metamorphics suggests that it is definitely intrusive.

The normal granites are al coarse-grained with a tendency to seriate texture, and consist essentially of quartz, microcline (or orthoclase), with chloritised biotite as the ferromagnesian. In all sections examined, epidote and zoisite were abundant, with apatite as the chief accessory. The plagioclase is invariably saussuritised, whereas the microcline is comparatively fresh. Where these two minerals occur close together there is frequently a development of myrmekitic texture (Fig. 3).

Fig. 3. Photomicrograph showing development of vermicular quartz at the contact of zoned plagioclase and microcline. Crossed nicols x 40.

Photo. H. Smith.

Unaltered biotite is a comparatively rare mineral, as it is mostly changed to greenish chlorite associated with epidote. It occurs in sheaf-like aggregates associated with granular epidote, euhedral apatite, and allotriomorphic quartz. Zircon inclusions surrounded by pleochroic haloes are abundant.

Epidote and zoisite are abundant, the latter mineral being typically developed in the plagioclase felspar.

The granite outcropping several miles North-West of the area is very similar in mineral composition and micro-structure to the Southern granite, and probably is part of the same bathylith.

Rock type (9629) is a granitic rock of rather fine grain, which occurs in contact with steeply dipping quartzite in Fault Creek (a small tributary of Poison Creek). In thin section the rock is very similar to the normal granite, with the exception that felspar exhibiting microcline twinning is absent. The felspars are all water clear, and contain numerous perfect muscovite rods which appear to have been re-crystallised. The felspar is all oligoclase. Chloritic biotite is the ferromagnesian as in the normal granite. Epidote is scarce and the main accessory is apatite. The fresh character of the felspars suggests that the rock is of later crystallisation than the normal granite. It may be a fault intrusion, i.e., a granitic dyke that has come in along the fault plane, subsequent or contemporaneous with the fault, but re-crystallised muscovite suggests that the rock is probably re-crystallised gneiss.

(b) *Pegmatite, Aplite, and Garnet-Muscovite-Granite.*—These are later than (a) above, as they intrude both the granite and the metamorphics. This phase appears to have followed closely upon the granitic intrusion, as the pegmatite dykes occur in greatest abundance in the metamorphics near the granite contact. The pegmatite phase may be conveniently sub-divided into: —

(i) Pegmatites proper—having very coarse texture. They occasionally contain such minerals as molybdenite, columbite, and beryl. The pegmatites consist essentially of quartz and alkaline felspar, with extensive development of muscovite in books and flakes up to 1in. diameter. The pegmatites grade into—

(ii) Garnet-muscovite-granites.—These granites have a medium equigranular texture, and consist essentially of quartz, alkaline felspar, plagioclase felspar, and muscovite, with numerous small pink garnets dotted throughout the rock.

The texture in thin section is allotriomorphic granitic, all minerals except muscovite and garnet being allotriomorphic. The felspars are microcline, which occurs in clear plates up to 1·5 mm. diameter, and oligoclase in clouded allotriomorphs averaging 0·6 mm. diameter. A noticeable feature is the absence of the myrmekite common in the normal granites.

Muscovite is abundant in lath-shaped crystals up to 0·8 mm. long. Secondary muscovite in cloudy aggregates is present in the felspars as the result of sericitisation. Biotite is rare in this type and isolated individuals only are to be found.

Garnet is present in all specimens—it occurs euhedral and its average size is approximately 0·8 mm. The garnets contain inclusions of quartz which occurs in small rounded blebs.

Minute zircons are the only other accessory, and have only been noted in one section, where they occur as inclusions surrounded by a pale pleochroic halo, in the muscovite.

(iii) Garnetiferous Aplites.—These are the fine-grained equivalent of the garnet-muscovite-granites. The prevailing texture is fine equigranular granitic. In thin section the texture is fine-grained, allotriomorphic granitic, and the rock consists chiefly

of quartz, microcline, and oligoclase, with accessory chloritised biotite and small pink garnets. The quartz occurs in irregular allotriomorphs usually about 0·25 mm. in diameter, forming a mosaic with the microcline. The garnets are small, averaging from 0·2 mm. to 0·3 mm. in size. Members (ii) and (iii) of the pegmatite group differ from each other in the prevailing finer grain, the absence of muscovite and the smaller size of the garnets in the aplites (iii).

The relations of the pegmatite, aplite, and normal granite are shown by Fig. 4, which is a drawing of a specimen collected near the head of Yinnerding Creek, which shows a pegmatite vein in the normal granite.

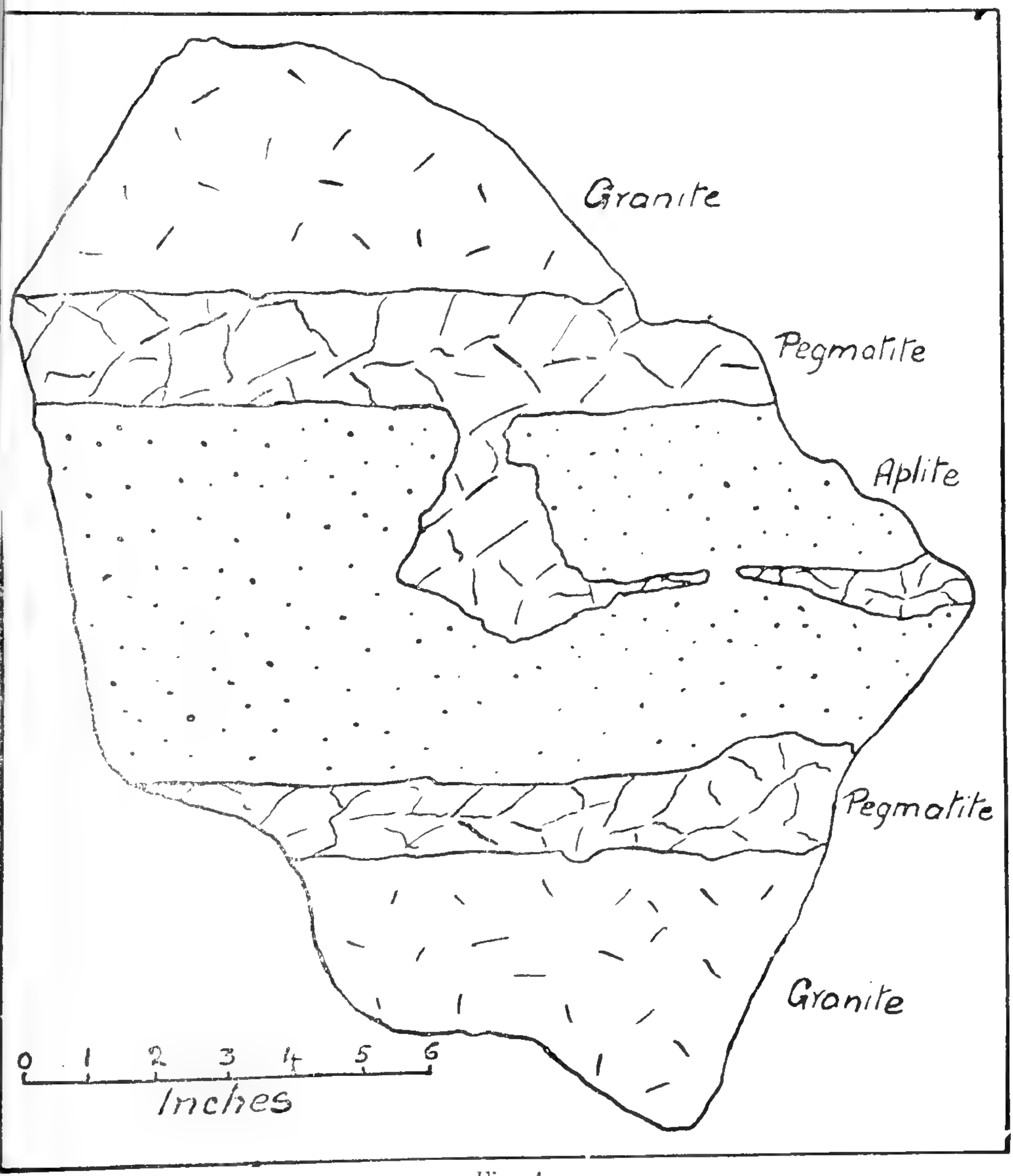


Fig. 4.

(c) *Quartz Veins.*—Quartz veins are of frequent occurrence, one or two are seen clearly cutting across the metamorphics, and it is reasonable to suppose that the frequent occurrence of scattered quartz boulders mark similar veins. As yet, the relation of the quartz veins to the pegmatite phase has not been discovered, but it appears likely that they have followed closely on the pegmatite-aplite dyke phase. Macroscopically the vein quartz is massive granular, consisting entirely of quartz grains. In thin section the vein quartz consists of large interlocking grains up to 5 mms. in diameter, containing innumerable small dust-like inclusions.

2. *Basic Intrusives :*

The basic dyke rocks present in this area represent the latest period of intrusion into the Jimperding Series, and whether they occur in the granite or in the metamorphics, appear to have a uniform mineralogical composition throughout the area. Most of the dyke rocks have the typical doleritic texture, except where it has been obscured by uralitisation of the pyroxene.

The basic intrusives are divisible into two main types :—

(a) *Dolerites.*—The dolerites form the major division of the basic intrusives. Macroscopically they are of variable grain from fine basaltic to coarse gabbroid. Whatever the grain size, the rocks are mostly equigranular. In thin section the ophitic texture is well developed except where obscured by uralitisation. The most abundant mineral is slightly brownish, non-pleochroic pyroxene, occurring in euhedral to subhedral plates ophitically enclosing felspar laths. In convergent polarised light, sections which show oblique extinction exhibit a pseudo-uniaxial figure, indicating a small axial angle for the pyroxene, which appears to approach closely the enstatite-augite series (Thomson, 1911), or pigeonite (Barth, 1931).

Most of the pyroxene shows uralitisation to some degree—alteration proceeds from the outside towards the centre of the pyroxene plates and appears to be more prevalent in the presence of ilmenite.

Hornblende often appears as a primary mineral in these dolerites, and is present in euhedral forms. The hornblende is intensely pleochroic (brown to dark green), and is idiomorphic towards the quartz.

The felspar is labradorite—it occurs as water clear or saussuritised laths up to 0·5 mm. x 0·15 mm. intergrown ophitically with the pyroxenes. Saussuritised felspar may be abundant in sections showing but little uralitisation.

In the quartz dolerites the felspar invariably occurs in micro-pegmatitic intergrowth with quartz.

The accessories are apatite, iron ore, and a little biotite. The apatite which occurs in euhedral rods and prisms showing cross fracturing, is most abundant in types with free quartz.

Ilmenite is most abundant in the quartz dolerites, where it occurs in large grains and skeleton crystals (up to 0·8 mm. diameter) showing alteration to leucoxene along crystallographic directions. In sections in which no free quartz is visible the iron ore appears fresh, despite the uralitisation of the pyroxene, and therefore appears to be magnetite. Pyrite is only present in small amount in the dolerites, and is absent from the quartz dolerites.

(b) *Epidiorites.*—This group is very similar to the dolerites, differing from them only in the degree of uralitisation, and requires no further detailed description. No definite regional distribution of the dolerites, quartz dolerites, and epidiorites has been recognised in this area, and no evidence is present of more than one period of basic dyke intrusion.

D.—LATER ROCKS :

1. *Duricrust :*

The ferro-aluminous duricrust (Woolnough, 1930, p. 125—generally referred to in papers on Western Australian geology as laterite) occurs in the South-Western part of the Jimperding Area, where it has been formed over the normal granite. The duricrust level in this region lies between 850ft. and 950ft. above sea level, being higher by 300ft. in this part of the Darling Range than in areas farther South (Clarke and Williams, 1926). In the North-Eastern block the land rises to the duricrust level in a few places, the duricrust occurring as knolls overlying gneiss or quartzite. The same rock of the Darling Range has been described elsewhere under the name of laterite (Simpson, 1912 ; Clarke, 1919).

In the North-Eastern section of the Jimperding Area the duricrust appears to have formed over the very siliceous quartzites. The first stage in the formation of duricrust over quartzite areas appears to be the coating and staining of the quartz grains with reddish oxide, but no intermediate stages between the iron-stained quartzite and the solid duricrust have been found.

2. *Talus Banks :*

The disintegration of the quartzite gives rise to many talus slopes. North of the Jimperding Brook and East of the head of Boundary Creek, an accumulation of talus about 10ft. thick is being cut through by a small stream. The talus consists of angular fragments of quartzite embedded in a hard clayey matrix, and appears to have accumulated in a basin-shaped hollow. The stream is at present cutting down into the deposit.

To the West of Boundary Creek a definite talus bank occurs as a cliff about 12ft. in height on the side of the hill facing Jimperding Brook. This talus bank is composed of iron-stained angular quartzite fragments embedded in a ferruginous matrix. This occurrence may be explained as an accumulation of talus cemented by limonite, when the river stood at a higher level, which has since been eroded into its cliff-like form.

3. *Alluvium and Alluvial Gold :*

Alluvium occurs along the flood plains of Jimperding Brook and Avon River. It consists of fine soil containing abundant silvery muscovite flakes. In the bed of the brook the material is coarser sand with rounded boulders (mostly quartzite).

The presence of alluvial gold in this area has been noted only in Yinnerding Creek, and although much work has been done in the area, all efforts have failed to find any primary gold-bearing formation.* The gold occurs in small fragments, the angular character and fineness of which suggest either that it has suffered little transportation, probably owing its origin to the pegmatitic and other acid bars which cut through the roof pendant at the head of the creek, or that there has been solution and secondary deposition of the gold in the alluvium. Should the primary gold-bearing formation occur in the schists at the head of Yinnerding Creek, there appears to be little possibility of any considerable lateral extent or persistence in depth for the formation, as geological mapping indicates that these schists form a small roof pendant in the granite, and consequently may not extend to any great depth.

* Since this paper was written I am informed that about 50 tons of ore from quartz leaders in the schist have been crushed for a yield of 15 dwt. per. ton.

IV.—THE ORIGIN OF THE METAMORPHIC ROCKS.

In the absence of chemical analyses of the rocks of this series, field evidence seems likely to give the most useful and reliable criteria for determining the nature of the original rocks.

At this stage it will be convenient to consider each set of rocks, and to summarise briefly the field and microscopical evidence detailed elsewhere, regarding the nature of the original rocks and the processes of metamorphism.

1. *Quartzites :*

A.—*Field Evidence :*

(a) Bedded appearance (Fig. 1).

(b) Persistence in bands of uniform thickness.

(c) Highly siliceous composition.

B.—*Microscopical Evidence :*

(a) General absence of cataclastic structure indicating re-crystallisation.

(b) Presence of oriented mica rods.

The field evidence clearly indicates a sedimentary origin for these rocks, and the microscopical evidence indicates that the rocks were formed under high pressure acting vertically downwards so that the mica flakes crystallised normal to the direction of the impressed force, in a zone where re-crystallisation was the dominant process.

2. *Acid Gneisses :*

A.—*Field Evidence :*

(a) Interbedded with quartzites of supposed sedimentary origin.

(b) Variability of texture and composition across the strike.

(c) Persistence of thickness and outcrop of the upper gneiss.

B.—*Microscopical Evidence :*

(a) Absence of cataclastic structures.

(b) Mineralogical composition similar to that of the normal granite.

(c) Presence of myrmekite.

So far as field evidence goes, the gneisses might have been originally—(1) sediments, (2) granitic sills, or (3) contemporaneous acid flows. The evidence of variation of composition across the strike and of great thickness of the upper gneiss, supports the sedimentary hypothesis rather than the granitic sill theory. The microstructures are indicative of recrystallisation. The mineral association (biotite, epidote, microcline, oligoclase and quartz) is similar to that of the normal granite, but this may be explained by recrystallisation under Grubenmann's mesozone conditions (Leith and Mead, p. 189), where the dominant process is recrystallisation (note absence of cataclastic structure in the gneiss) and remineralisation with the above minerals characteristic.

It appears, however, that very detailed petrological work will be necessary before any definite conclusion is reached regarding the origin of the gneisses. The evidence at present available appears to be slightly in favour of the sedimentary hypothesis.

3. *Basic Schists and Hornblende Gneisses :*

A.—*Field evidence :*

(a) Bedded arrangement.

(b) Presence of andalusite crystals in the mica-schist which immediately overlies the upper basic schists, and decrease in size and abundance of andalusite with increasing vertical height above the basic schists.

B.—*Microscopical evidence :*

(a) Presence of schistose structure and absence of cataclastic effects in the quartz.

(b) Presence of rims of recrystallised sphene surrounding iron ores (in the lower hornblende gneisses).

The field evidence suggests that the basic schists and hornblende gnesises may have been basic sills or flows. The assumption that the upper layer of basic schist was originally a basic sill, is supported by the distribution of andalusite in the overlying schist.

The microscopical evidence indicates that shearing or rock flowage (Leith and Mead, p. 222) was necessary to generate the textures observed. The assumption of shearing having produced the schistose structure is in accord with the quartzite and acid gneiss micro-structures only if this shearing was followed by recrystallisation. The andalusite crystals show no signs of distortion which would be expected under conditions required for the formation of the hornblende gneisses, but this may be explained by the fact that the andalusites are embedded in an incompetent matrix which would probably absorb most of the stress.

The presence of sphene rims around iron ore supports the view that the hornblende schists result from the metamorphism of basic igneous rocks (Teall, 1885), (p. 133).

4. *Mica Schists :*

(a)—*Field evidence :*

Conformable with the quartzites which are regarded as sedimentary.

(b)—*Mineralogical evidence :*

Presence of andalusite.

These schists are characterised by a high alumina content as evidenced by the presence of andalusite, a typical mineral of meta-sediments.

5. *Conclusion :*

Considered generally, the available evidence favours the hypothesis that the Jimperding Series is a series of meta-sediments with intercalated meta-igneous rocks, represented by basic schists and hornblende gneisses. The original nature of the gneissic bands is very doubtful. In the process of metamorphism in the Jimperding Area the earlier forces appear to have been dominantly of directed character, producing schistose structure of the hornblende gneisses and granulation in the quartzites. With later change to lower zone (probably mesozone) temperature-pressure conditions, the forces appear to have been mainly hydrostatic, promoting recrystallisation and production of granoblastic allotriomorphic to granoblastic gneissic micro-structures.

V.—GEOLOGICAL HISTORY OF THE AREA.

The greater part of the area which has been mapped in the Jimperding Valley consists of a series of meta-sediments which have been intruded by later acid and basic intrusives.

The metamorphics consisting of a conformable series of quartzites, gneisses and schists which were probably represented originally by sandstones, grits and mudstones are definitely older that the Darling Range granite, and were probably laid down in early Pre-Cambrian times (probably Yilgarn) (Maitland, 1919). These sediments contained intercalated basic flows and were invaded by basic sills. They were deeply buried, and finally intruded by igneous rocks. The main intrusion was the Darling Range granite bathylith, which was probably instrumental in effecting the greater part of the metamorphism, followed by intrusion of acid dykes, which appeared to follow closely on the granitic intrusion.

The last phase of igneous activity is represented by the basic dyke rocks which intruded all the pre-existing rocks.

The area was now subjected to long continued erosion and there is no evidence of accumulation on it of extensive sedimentary series since the deposition of the Yilgarn (?) sediments. Farther to the South-West in the Bullsbrook district, leaf-bearing shales, possibly of Jurassic age, are found overlying gneiss, but they are absent from the Jimperding Area.

The superficial duricrust belongs to a recent period when the greater part of W.A. was reduced to a peneplain (Woolnough, 1918), and, since this time, the area has been dissected by streams as outlined in the physiographic section of this paper.

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2.—THE LIMESTONE OF THE SWAN COASTAL PLAIN: ITS USE AS A BUILDING STONE

by

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CONTENTS.

I.—INTRODUCTION.

The limestone concerned with in this paper occupies hills and ridges, slightly elevated above the Swan Coastal Plain, running parallel to the west coast of Western Australia. The principal localities in which the stone is quarried are shown on the sketch map (Plate I.). Although it is called

* This paper was prepared during the tenure of a Hackett Studentship in the Department of Geology, University of Western Australia.

limestone, the stone often contains a large percentage of sand, some varieties being indeed calcareous sandstones.

Towards the end of 1929 about ten samples of coastal limestone were analysed by S. E. Coalstad in the Chemistry Laboratory of the University of Western Australia. One object of the analyses was to compare the Coogee stone being used in the construction of the University Hackett Buildings with stones from other localities. The data obtained by Coalstad led to the asking of the following questions:—

(a) Why is 9398 (one of the samples) harder than the other samples?

(b) Is different porosity associated with different mineral composition?

Partial answers to these questions were given by R. A. Hobson, who examined the samples petrographically and submitted his results in a report to the Vice-Chancellor of the University. However, owing to the limited number of specimens available for examination, it was thought necessary to continue the investigation into the properties of the coastal limestone, and a Hackett Studentship awarded to me in 1930 enabled this more complete investigation to be made.

In January, 1930, I commenced work on the coastal limestone with the following objects in view:—

(1) To compare the Coogee (Hackett) stone with other coastal limestones used for building purposes;

(2) To answer fully the questions (a) and (b) which Hobson, owing to limited time and to a limited number of specimens, only partially answered;

(3) To give builders some idea of the properties of the coastal limestone and to furnish data which would be useful to them in selecting stones for various purposes;

(4) To determine whether it is possible to give some indication of the compressive strength of the coastal limestone from data such as porosity and insoluble content.

Approximately forty samples of stone suitable for building purposes have been collected from various quarries between Balcatta and Coogee. The localities are referred to as locality A, locality B, etc., and the quarries as No. 1, No. 2, etc. The individual samples of stone have been added to the rock collection of the Department of Geology, University of Western Australia, and each sample thus has its own catalogue number (*e.g.*, 9398).

TABLE 1.

List of Samples Examined.

Catalogue Number of Sample.	Quarry No.	Locality.
9223 (a) and (b)	1	A
9389, 9390	2	
9391, 9392	3	
9224, 9225, 9226, 9227	4	B
9399	5	
9235, 9236	6	C
9237, 9238, 9239	7	
9386, 9385, 9387, 9388	8	D
9395, 9396, 9397, 9398	9	
9228, 9229, 9230	10	E
9231, 9232, 9233	11	
10486	12	F

In collecting samples I am indebted to K. C. Tiller of the Education Department, who motored me to the various quarries and, in addition to help in the field, kindly lent me his thesis entitled "The Sedimentary, Engineering, Building and Ornamental Stones of the South-West Geological District." I am also indebted to Messrs. A. T. Brine & Sons, Contractors, who have given me permission to use their compressive strength data.

The laboratory work, with the exception of the compressive strength tests, was carried out in the Department of Geology, University of Western Australia, under the supervision of Professor E. de C. Clarke, to whom I am greatly indebted for suggestions and advice.

II.—MODE OF OCCURRENCE.

The coastal limestone in the vicinity of the Swan River was described over one hundred years ago by the Rev. Archdeacon Scott (1831, p. 320). An abstract reads as follows:—

> The author, who was accidentally detained at the settlement recently established on the western side of Australia, describes a line of coast of more than thirty miles in length, composed of a highly calcareous sandstone, presenting very similar mineralogical characters throughout its whole extent. At a promontory about five miles to the north of the river Swan the calcareous sandstone exhibits a surface in which are numerous concretions having the appearance of enclosing vegetable matter. This character is by no means confined to this spot but is very commonly observed; and on a rising ground to the east of the space marked out for the intended town of Fremantle, the sandstone assumes the appearance of a thick forest cut down about two or three feet from the surface, so that to walk on it becomes extremely difficult and even dangerous.

The south coast of Garden Island presents a typical example of what Scott noticed near Fremantle. I visited Garden Island in 1930, prior to reading Scott's paper, and was particularly impressed by the stump-like appearance of the limestone, some of the "stumps" measuring about three feet in height and two feet in diameter, with perceptible widening at the base.

However, when quarried the coastal limestone presents a different aspect. In most quarries there are several types of material as follows:—

(1) Capstone, a hard crust in layers more or less parallel to the surface, quite frequently covered or partially covered with soil;

(2) Root-like tubes of stone irregularly ramifying in all directions. The constituent "roots" are roughly cylindrical, usually about ½ inch in diameter, and in between them is loose calcareous sand. The term *"network"* is suggested for this structure;

(3) Trunks or large pipes, cylindrical or slightly tapering bodies (made up of hard stone somewhat similar to the capstone), essentially straight and vertical and of some size—up to one foot in diameter. They always extend right up to the surface;

(4) Bedded stone which alone is quarried for building purposes.

There are two types of quarry along the coast between Balcatta and Coogee, one type consisting of capstone, bedded stone containing organic matter and bedded stone devoid of organic matter; and the other consisting of capstone, network and bedded stone without organic matter. I think that the two types of quarry represent two stages in the development of the limestone. In the first type organic matter is present; in the second type the

organic matter has been completely removed and the roots have been petrified. The terms "juvenile" and "mature" are suggested for the first and second types respectively (Fig. 1).

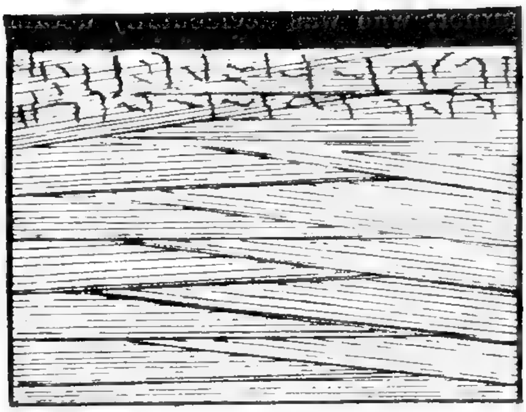

Fig. 1.—Diagrammatic representations of Mature and Juvenile types of quarry. (a) Mature Type, Quarry No. 8, locality D; (b) Juvenile Type, Quarry No. 3, locality B.

The depths of the zones below the surface are extremely variable. Descriptions of several quarries may serve to indicate the degree of variation.

Quarry No. 6, locality C, a typical example of a mature quarry, consists of capstone, network and bedded stone. The capstone and soil are about a foot or two in thickness, and they are immediately followed below by the network which in one place extends down to the base of the quarry (some twenty feet or so), and in other places extends to a depth of about twelve feet below the surface. This zone consists of a network of small, more or less cylindrical tubes, about ½in. in diameter, which are quite hard and dense. They have been built up by concentric shells or cylinders of carbonate of lime. Some of them contain definite air-passages through their centres, and in several, thin thread-like carbonaceous fibres form the central cores around which the carbonate of lime has been deposited. The presence of small black specks, seen quite clearly in end-sections of the tubes, suggests organic matter. The spaces between tubes are filled with incoherent sandy material.

The network in Quarry No. 8, locality D, is similar to that in Quarry No. 6, locality C, and the zone occupies a few feet in depth in most places, whilst in an old quarry face it extends down some 12 to 15 feet to the base of the quarry. There is also a trunk or large pipe which penetrates the bedded stone (Fig. 1 (a)).

Quarry No. 3, locality B (Fig. 1 (b)), is typical of the juvenile type. The overburden in the quarry is very small, practically amounting to a thin veneer of capstone and soil; but for three or four feet from the surface excellent quality stone is everywhere penetrated by roots and decayed organic matter which render it useless as a building stone. Network and pipes are completely absent.

Quarry No. 4, locality B, is another juvenile type. The capstone outcropping at the surface through red soil, extends down to a depth varying from one foot to about ten feet in the form of huge pipes surrounding organic matter. The network characteristic of the mature type of quarry is completely absent.

Beneath the capstone in the juvenile type, and beneath the network in the mature type of quarry is the bedded (current-bedded) stone. The current-bedding is of two types, large scale current-bedding in which the bedding is uniform over large distances (30 feet or more), and small scale current-bedding in which the bedding changes its direction within a foot or so. Many blocks of stone, 3ft. x 2ft. x 2ft. in size, with only one bedding plane may be quarried from the large scale type, whilst in a single block of the same size from the small scale type there may be many changes in the direction of the bedding planes.

Both large and small scale current bedding may be observed in any one quarry irrespective of whether it belongs to the juvenile or to the mature type. The stone from large scale current-bedding is usually of a better quality than small scale current-bedded stone, but this is not general, for in one quarry (quarry No. 7, locality C), some of the finest "shoddies" (*i.e.*, carefully selected blocks of stone) contain small scale current-bedding. On the other hand, in quarries where large quantities of powder are used in blasting, small scale current-bedded stone is invariably shattered and is therefore useless as a building stone. Quarry No. 3, locality B, is an example of this, but I believe that the waste so produced is used for road construction.

In some quarries bedding planes are very well marked, whilst in others no bedding planes can be seen.

III.—PETROLOGY.

A General Description.

Macroscopic.

The colour of the coastal limestone varies from pale ash-grey, through white and cream to buff, depending to some extent upon the nature of the constituents. The white, cream and pale buff stones are usually soft and chalky, or soft and spongy, whilst the more coloured varieties are hard, slightly brittle and very rarely spongy. The colour appears to be largely influenced by the grain of the stone, for the white stones are as a rule extremely fine grained, composed of finely divided calcium carbonate which rubs off easily as a chalky powder, whereas the coloured stones are made up of white, yellow, brown, red and violet shell fragments, with waxy and frosted grains of quartz.

All stones can be cut with an axe but with different degrees of ease. Some of the very hard buff coloured stones give a metallic ring when struck with a hammer, while the soft white stones emit a dull thud. The white chalky or spongy stone is largely in demand for bungalow foundations, principally because it can be shaped readily with an axe.

Microscopic.

The principal constituents of the coastal limestone revealed by the microscope, are fragments of calcium carbonate, quartz grains and a cement of calcium carbonate. Occasionally grains of felspar (microcline, orthoclase and plagioclase) can be seen, and in one section a grain of epidote was noticed. Rutile needles are very abundant as hair-like inclusions in the quartz grains. Minerals apart from quartz and felspar are thus rare, but in a sample of stone from Cape Leeuwin, a large assemblage of minerals was noted, in which were included quartz, felspar (several varieties), hornblende, ilmenite, magnetite, garnet, apatite and augite.

The carbonate fragments consist of small shells or parts of shells, and opaque grains in which shell structure cannot be seen. The shells are mostly foraminiferal tests (whole or fragmentary) and oval-shaped mollusc fragments. An occasional sponge spicule occurs. Among the foraminifera are forms resembling Discorbina, Miliolina, Textularia, Cristellaria and Globigerina. The size of the carbonate fragments varies from less than 0.01mm. up to 2mm. in diameter. It is usual to find that the shell fragments in stone from the mature type of quarry are less well preserved than those in stone from the juvenile type of quarry.

The quartz grains are rounded to angular and vary greatly in size, the smallest being less than 0.01mm. and the largest measuring up to 2mm. in diameter. The largest grains are invariably well rounded, while the smallest are angular. Medium-sized grains have no definite shape (Fig. 2).

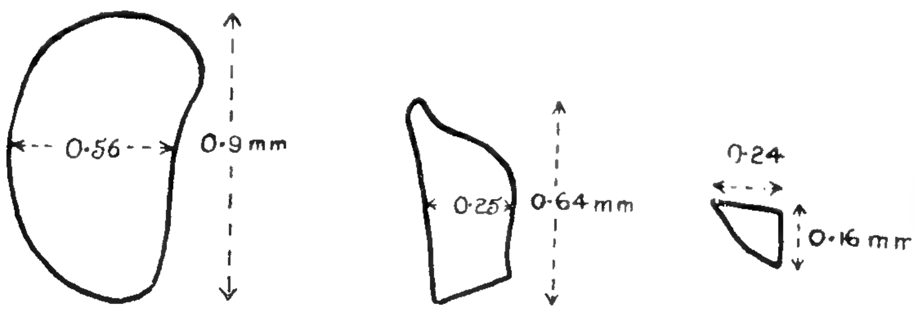

Fig. 2.—Typical quartz grains.

The cement varies considerably in distribution. In some stones it acts as a definite matrix binding the shell fragments and quartz grains together, but in others the shell fragments are fused to each other by a thin film of cement which is continuous with, and part of, each shell fragment. The cement appearing as a matrix is made up of minute grains of calcium carbonate, not in crystalline continuity. Usually it is very irregularly distributed. In some stones it forms a fairly thick layer around quartz grains, especially very large grains, whereas the shell fragments possess mere films of cement. In other stones, both quartz grains and shell fragments are liberally coated with cement. In all stones, however, there is never a complete filling of the spaces between the grains. There are thus many air spaces which account for the high porosity of the stone. The amount of air space depends on the closeness with which the grains are packed and the nature and distribution of the cement. It is therefore convenient to describe the various types of stone under the heading of "Textural Types," and as will be shown later, the hardness, density and porosity of building stones of the Swan Coastal type, depend largely on texture.

B TEXTURAL TYPES.

Under the heading of texture are considered the size and shape of the individual grains, their relationship to each other and the nature and distribution of the cement. The most noticeable differences in the coastal limestone are, however, the size of the grains and the closeness of packing and consequently the stones are dealt with under these headings.

It must be emphasised here that in all stones, irrespective of grain size, no hard and fast lines can be drawn between those in which the grains are closely packed together and those in which the grains are widely separated, for there is every perceptible gradation between the two. It is however convenient to divide the stones into two types, close grained and open grained, which represent the two extremes of texture.

It is usual to find that stones from the mature type of quarry, where networks are abundant, are open grained, and the shell fragments found in these stones are less well preserved than those found in the juvenile type of quarry. The cement, though patchy, is more abundant in "mature" stone than in "juvenile" stone, where the cement usually amounts to a mere film coating the grains rather than a definite filling or matrix. Suggested explanations for the differences between the stones selected from the two types of quarry will be given in another section of this paper (p. 40).

1. FINE GRAINED STONES.

(a) Close Grained.

Textural Type 1a.

The best example of a stone of this type is 9237 from a "shoddy" in Quarry No. 7, locality C. The stone is fairly compact, fine and even in grain, and is of a cream to pale buff colour. It is neither spongy nor friable, but is nevertheless very easy to shape. Bedding planes are well pronounced, even in a small 2in. cube block.

The even grained appearance of the hand specimen is very clearly seen under the microscope (Plate II., 1a.). Both quartz and carbonate grains are very tightly packed together. The quartz grains are irregular in shape but remarkably uniform in size. The largest grains do not exceed 0.25mm., while many do not exceed 0.16mm. Very small grains, 0.08mm. or less are also particularly abundant, but none of the grains are rounded. A few grains of felspar and an occasional grain of hornblende complete the mineral content of the stone.

The most striking feature of many of the fragments is their elongation along a direction more or less parallel to the bedding planes. Most of them are of molluscs but some appear to be sponge spicules. Foraminiferal tests are fairly rare, those present being difficult to identify.

The cement is distributed evenly throughout the stone as a mere film surrounding quartz grains. The carbonate fragments appear to be fused to each other, but where joined to quartz grains small bridges of cement are usually seen. Fig. 3 shows the way in which the grains are cemented.

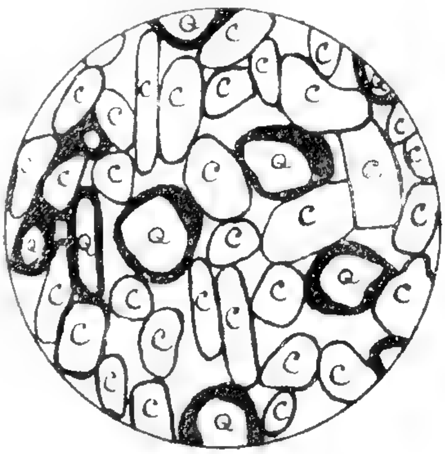

Fig. 3.—Nature of the cement in 9237 (Quarry No. 7, locality C).
Q, quartz grains; C, carbonate grains; cement is black. X about 30.

Under the high power the cement is seen to consist of finely divided calcium carbonate. This material rubs off the hand specimen as a chalky powder, but a magnification of 300 diameters produced by a high power objective shows it to consist of extremely minute grains.

Another stone belonging to this type is 9227 from Quarry No. 4, locality B. It is a very hard fine grained stone, efficiently cemented, and has the appearance of a hard sandstone. It is a little coarser in texture than the locality C stone described above. Quartz grains are comparatively few in number but they vary greatly in size and shape, only the large grains showing rounded forms. Though most of the grains are from 0.15 to 0.3mm. in diameter, there are a few very large ones (the largest measuring 1.5 x 0.65mm.) and some very small ones less than 0.1mm. in diameter.

A few grains of felspar are seen occasionally, and rutile needles are sometimes noticed as inclusions in quartz grains.

The carbonate fragments consist mainly of foraminiferal tests, many of which are well preserved, with a few fragmentary molluscs and a few opaque grains. All grains are closely bound together by a cement of calcium carbonate which is plentifully and evenly distributed. Two main differences can be observed between the nature of the cement in this and the stone from locality C. The first is that in this stone both quartz and carbonate grains are enclosed in the cement whereas in the locality C stone the quartz grains are cemented to each other and to the carbonate grains by a film of cement whilst the carbonate grains appear to be fused to each other. In other words the cement is confined to the quartz grains in the locality C stone, but in this stone it is shared alike by quartz and carbonate grains. The second difference is in the nature of the cement. As in the stone (9237) from locality C. the cement is granular, but the grains are very much larger and they appear to be definitely of crystalline calcite. The differences in hardness and porosity are probably due to these differences in the nature of the cement, for the locality B stone is very much harder than the locality C stone and it has a lower porosity. The question of differences in coherence will be discussed in another section of this paper.

(b) Open Grained.

Textural Type 1b.

The best example of this type comes from Quarry No. 6 locality C. The quarry belongs to the mature type in that it has the network between the cap and the bedded stones.

The stone from this quarry is very soft, friable and spongy, and its light weight indicates a high porosity. The colour is cream with a faint tinge of buff. It is a fine, even-grained stone and no quartz can be seen in the hand specimen without the aid of a powerful lens. The air spacing is very uneven and the stone appears to be very loosely coherent.

Under the microscope the texture is seen to be not nearly as even as it seems in the hand specimen (Plate II., 1b.). The quartz grains are extremely numerous and very irregular in shape (mostly angular), but they do not vary greatly in size. Large grains are absent and with the exception of a few grains measuring 0.5mm. in diameter, the grains are of the order of 0.2mm. or less in diameter.

The carbonate fragments are made up of opaque grains, transparent grains of calcite, and ill-defined shelly material of a very fragmentary nature;

and more or less evenly distributed among them are the quartz grains. The shell fragments are usually poorly preserved and recognition of the varieties is rather difficult. All fragments whether quartz or carbonate are fairly widely separated from each other by a non-plentiful and totally inadequate cement of calcium carbonate, leaving wide and irregular inter-granular air-spaces. In rare instances, the cement completely fills the spaces between grains, and unlike stone from quarry No. 7 (same locality), the cement is distributed around quartz and carbonate grains alike.

The cement is of the very finely divided type mentioned previously in connection with stone from the other quarry in this locality, and it seems quite general that the finely divided cement is characteristic of the mature type of quarry.

The stone from quarry No. 3, locality B, is another open grained stone but it differs in many ways from the stone in quarry No. 6, locality C. The quarry belongs to the juvenile type, and is made up of a thin veneer of soil and capstone followed by a zone of bedded stone containing organic material but no large pipes or network. The bedded stone is buff coloured, fine and even grained, moderately hard but a little spongy.

Under the microscope the stone is seen to be fairly even grained, most of the grains being about 0.3mm. in diameter. Mineral constituents (i.e., those other than carbonate) are not very abundant and consist almost entirely of angular quartz grains, with a few rounded grains here and there. The maximum variation in size of the quartz grains is 0.03 to 0.6 mm. An occasional grain of epidote and felspar can sometimes be seen.

The carbonate fragments consist principally of well preserved shells such as molluscs and foraminifera, with rounded or elongated opaque grains. The average size of the carbonate fragments is about 0.3mm., but larger ones (one of which measured 0.16 x 1.13mm.) are not uncommon.

The grains are usually not in contact with each other but are separated by a fairly coarsely granular cement of calcium carbonate which embeds both quartz and carbonate grains alike. This cement is fairly evenly distributed throughout the stone. Fig. 4 illustrates the relationship of the grains to the cement.

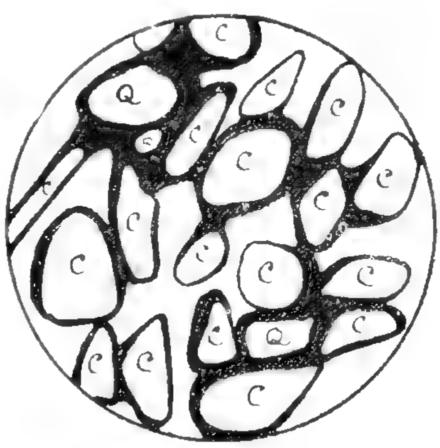

Fig. 4. Nature of the cement in 9391 (Quarry No. 3, locality B).
Q, quartz grains; C, carbonate grains; cement is black. X about 30.

2. MEDIUM GRAINED STONES.

(a) Close Grained.

Textural Type 2a.

9398, Quarry No. 9, locality D, analysed by Coalstad and petrographically examined by Hobson, is the best example of this type of stone. It is a dense hard stone, with an even, medium grain, consisting of rounded shell fragments, many of which are salmon-pink and brown coloured, and rounded, frosted grains of quartz.

Under the microscope the stone is seen to be fairly even grained, the quartz grains showing a greater range in size than the carbonate grains. Quartz is fairly common and occurs principally as angular or sub-angular grains, with very few of the large grains rounded or oval-shaped. They vary in size from 0.05 to 1mm., with an average size of 0.5mm. A few large grains of felspar are also present.

The carbonate fragments are mostly 0.4 to 0.5mm. in diameter with very few exceeding 0.5mm. They consist of fairly well preserved foraminiferal tests, fragmentary molluscs and opaque grains which cannot be recognised as shelly material.

All grains are closely packed together, nearly all touching and are well cemented. The cement is fairly evenly distributed, but is usually more abundant around quartz grains than around carbonate fragments. It is the very coarsely granular type of cement which appears to be characteristic of hard stones.

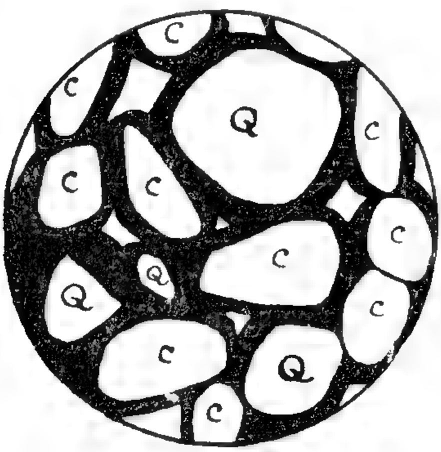

Fig. 5.—Nature of the cement in 9398 (Quarry No. 9, locality D).
Q. quartz grains; C. carbonate grains; cement is black. X about 30.

This sample (9398) was taken from the sea-wall where it had been exposed to the weather for over sixty years. Originally it came from quarry No. 9, loc. D. Hobson made three sections of the stone, one from the outside, weathered face, and two from the interior. The latter are better cemented than the outside one in that the cement is more plentiful, and the grains are more closely and efficiently held together.

Other stones belonging to this type are 9395, 9396 and 9397 from the same quarry (No. 9, locality D), and some samples obtained from Garden Island, which are a little finer in grain.

(b) Open Grained.

Textural Type 2b.

The stone from Quarry No. 1, locality A, selected as an example of this type, is a faint buff tinged stone with medium grain. Examination with a hand lens shows that the grains are not of uniform size. Quartz grains are particularly abundant and vary in size from less than 0.01mm. up to 1mm. in diameter. They all have a frosted appearance which is probably due to wind abrasion. The carbonate fragments are often pale brown in colour and do not show as much variation in size as the quartz grains. The average grain size is about 0.5mm.

The constituents of the stone seen under the microscope, are quartz grains and occasional fragments of felspar, carbonate grains (mostly tests of foraminifera and fragments of mollusc shells) and a carbonate cement.

The most striking feature observed in the thin section is the irregular grain due largely to the extreme variation in size of the quartz grains (Plate II., 2b.). In the best quality stone the large quartz grains average 0.7mm., and the smallest ones vary from 0.08mm. to 0.3mm. In general, only the very large grains (sometimes 1mm. or more in diameter) are rounded. The very small ones are angular and the medium size grains (0.2 to 0.7mm.) are sub-rounded. A few of the large quartz grains contain rutile needles (sagenite webbings).

The carbonate fragments are of two types, one type showing definite shell structure and the other, owing to opacity, showing no recognisable structure. The carbonate grains are rounded, elongated or oval-shaped, rarely angular.

The cement, which is of the very fine granular type, is very irregularly distributed throughout. The carbonate grains are practically devoid of cementing material and, where in contact with each other, they appear to cohere by only a very thin film, which represents the fringed boundaries of grains which have started to dissolve. On the other hand quartz grains frequently have thick coatings of cement (Fig. 6).

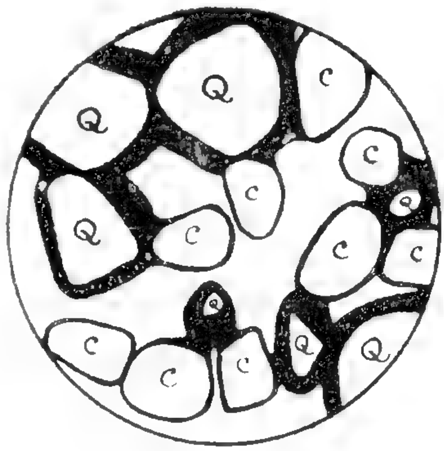

Fig. 6. Nature of the cement in 9223 (Quarry No. 1, locality A).
Q. quartz grains; C, carbonate grains; cement is black. X about 30

Another stone of this type was obtained from Quarry No. 11, locality E. This stone is similar in texture but a little harder and more efficiently cemented than 9223 (Quarry No. 1).

3. COARSE-GRAINED STONES.

Textural Type 3.

Only two (9400 and 9401) out of about forty different samples of limestone examined were found to be coarse grained. Both samples should strictly be regarded as sandstones, for their silica contents are over 50 per cent.

9400 is a very soft, white stone, containing rounded, waxy grains of quartz embedded in a white chalky matrix. The stone is easily shaped and when rubbed between the fingers disintegrates readily into quartz grains and chalk powder.

Under the microscope it is seen to consist principally of very large rounded, oval shaped or elongated quartz grains, and a few large shell fragments embedded in a finely divided spongy cement. The large quartz grains, some of which contain sagenite webbings, range in size from 0.5 to 2mm. A few small grains 0.1mm. and less in diameter are also present. Felspar is not plentiful, but a few large grains 1mm. in diameter can sometimes be seen. Shell fragments are very large but not abundant. They are mostly elongated or oval-shaped, and they appear to be principally

mollusc remains. The cement fills in the spaces between all grains but it is porous, and is very finely divided (Fig. 7).

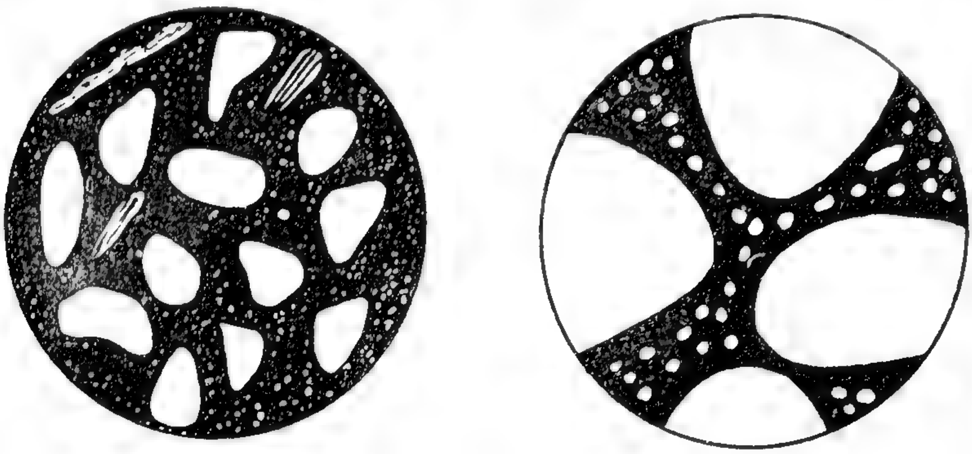

Fig. 7.—Nature of the cement in 9400. (a) x about 8, (b) x about 30. Quartz grains are colourless, shell fragments striped. The cement (black) is porous, the tiny colourless specks representing pore spaces.

9401 is very unlike 9400 in hand specimen. It is composed of large rounded, frosted grains of quartz, white, brown and salmon-pink coloured shell fragments, all cohering, apparently, without the aid of a cement. It thus has the appearance of a consolidated, coarse beach sand.

Under the microscope it is seen to differ from 9400 in that there are more shell fragments, all grains being more tightly packed together, many touching each other, and in that the cement is less abundant and less porous. Of these differences, which are undoubtedly responsible for the difference in the appearance of the hand specimens, the proportion of carbonate fragments to cement is probably the most striking. The two stones have approximately the same porosity and insoluble content, but whereas in 9400 most of the soluble material (principally carbonate) is in the form of cement, in 9401 it takes the form of shell fragments.

IV.—LABORATORY DETERMINATIONS.

A—Porosity.

In this paper the porosity of a stone is expressed as the percentage by volume of air-space, calculated on moisture-free stone. The method of determination employed is briefly as follows:—

A block of stone about 4 cubic inches in volume is dried at 130° C. and water slowly added until the water level is about ¼ inch above the top of the block. The water is boiled for twenty minutes, and the boiling repeated twice at intervals of twenty-four hours. The block is then suspended from the arm of a balance by a thin thread and weighed under water. It is then removed from the water, dried quickly with some absorbent material, and weighed on a clock glass. It is then dried again at 130° C. and reweighed. The difference in weight (usually very small) at the commencement and at the end of the experiment gives the amount of material detached from the stone during boiling, handling and drying. Corrections are made for the amount of detached material. From the data so obtained, the porosity, bulk density and the density of the material in the stone are calculated.

In obtaining the density of the material in the stone, a check on the accuracy of the experiment is obtained.

Example:

Estimation of Porosity, etc.

Locality:	B, Quarry No. 3.
Sample No.:	9392.
Treatment:	Preliminary and final drying (130° C., 4 hrs.)
Weight of block	101·17 gm. (prel. drying); 101·15 gm. (final drying).
Weight of water-logged block under water ...	63·83 — ·08 (Wt. of thread) gm.
Weight of water-logged block in air ...	136·35 gm.
Weight of water absorbed	35·18 gm.
Volume of water absorbed	35·18 ml.
Volume of material in block	101·17 — 63·75 — 37·42 ml.
Total volume of block	72·60 ml.
Porosity $\left(\dfrac{\text{Vol. air-space x 100}}{\text{Total volume}}\right)$	$\dfrac{35 \cdot 18 \times 100}{72 \cdot 60} = 48 \cdot 5\ \%$
Bulk Density $\left(\dfrac{\text{Wt. of stone}}{\text{total volume}}\right)$	$\dfrac{101 \cdot 17}{72 \cdot 60} = 1 \cdot 39$
Density of Material $\left(\dfrac{\text{Wt. of stone}}{\text{vol. material}}\right)$ ...	$\dfrac{101 \cdot 17}{37 \cdot 42} = 2 \cdot 70$

The value of 2.70 for the density of the material of the block is roughly a constant for most of the coastal limestones. It does vary slightly, from 2.68 to 2.72, depending on the insoluble percentage. In this instance the stone contains 17 per cent. silica (S.G. = 2.65) and 83 per cent. carbonate (S.G. = 2.175). The density of material in these proportions, calculated from the Specific Gravities given, is 2.70.

Compared with the average limestone found in England, the coastal limestone is a very porous stone. Forty samples tested gave a range in porosity from 17 per cent. to 57 per cent., with an average value of about 40 per cent. On the other hand, limestones from England give an average value of about 20 per cent., with values in some stones, as low as 8 per cent. The least porous stones of the coastal limestone type have therefore approximately similar values to those of the most porous stones found in England. Table 2 shows the number of stones tested with their ranges in porosity.

TABLE 2.

Number of Samples.	Range in Porosity.
1	Under 20 per cent.
4	20—30 ,,
12	30—40 ,,
13	40—50 ,,
7	Over 50 ,,

A very important feature of the coastal limestone is the nature of the pore spaces. From microscopic examination, and from the fact that the density of the material in the stone, calculated from the porosity data, is

fairly constant, it is obvious that the pore spaces are in direct communication with the atmosphere. Each pore space can therefore be occupied by water, so that weighing a block of water-logged stone under water is equivalent to weighing the same amount of powdered material in a density bottle; hence the constant density, 2.70. The importance of this will be shown in subsequent sections of this paper.

The facing stones most in demand are those whose porosities range from 35 per cent. to 45 per cent. For ordinary bungalow foundations, stones with values from 40 per cent. to 55 per cent. are used. Stones with values lower than 35 per cent. are rarely used because they are usually hard to shape.

The high porosity of the coastal limestone is due to the inadequacy of the cement. In many stones, coherence is obtained by thin films of cement which are really the recrystallised surface coats of carbonate grains which had commenced to dissolve in rain water containing carbon di-oxide. An explanation of the formation of the cement will be found in a subsequent section of this paper (p. 40). In other stones because of uneven grain the cement is very patchy (*e.g.*, the stone from locality A) and in two stones (9400 and 9401) the cement is abundant but is of a spongy nature.

In the following table (Table 3) are given the ranges in porosity of stones from various localities.

TABLE 3.

Locality.	Range in porosity.	Number of samples.
A	41—44%	4
D	24—51%	8
C	39—55%	5
E	35—55%	6
B	18—48%	7
Garden Island ...	25%	1

B INSOLUBLE CONTENT.

Like porosity, the acid insoluble content (commonly referred to as "sand") is extremely variable, ranging from 5 per cent. to 66 per cent. The average value, based on thirty-six analyses, is, however, only 23 per cent. The reason for such a low average is due to the fact that in most of the samples the insoluble content is under 30 per cent. Table 4 shows the number of samples analysed and the ranges in insoluble content.

TABLE 4.

Number of Samples.	Range in Insoluble Content.
20	Under 20 per cent.
8	20—30 per cent.
5	30—40 per cent.
3	Over 40 per cent.

Petrographic examination has shown that the insoluble material is almost entirely silica (quartz) and that the amount of heavy minerals is negligible. It has also shown that the reason for such a wide range in the insoluble content is due to differences in grain size. Stones with uneven grain, such as those from locality A, and coarse grained stones such as 9400 and 9401 have very high insoluble contents whilst fine grained stones (*e.g.*, those from locality B) have low insoluble contents.

Table 5 shows the range in insoluble content of stones from various localities.

TABLE 5.

Locality.	Range in Insoluble Content.	Number of Samples.
A	31—50 per cent.	4
D	16—33 per cent.	8
C	12—29 per cent.	5
E.	8—21 per cent.	6
B	8—17 per cent.	7
Garden Island ...	5 per cent.	1

C. COMPRESSIVE STRENGTH.

Tests for compressive strength of the coastal limestone have been carried out at the School of Engineering of the University of Western Australia during the course of erection of the Hackett Memorial Buildings, and I have obtained permission from Messrs. A. T. Brine and Sons, Contractors, to use the data obtained.

The range in compressive strength of the coastal limestone shown by over forty tests, is very great from 10 tons and less per square foot up to 318 tons per square foot. However, stones with a compressive strength exceeding 150 tons per square foot are exceptional, and, as can be seen from Table 6, two-thirds of the samples tested gave values less than 30 tons per square foot. An approximate average value, based on samples of building stone commonly used, is 25 tons per square foot.

Table 6 shows the number of samples tested, with their ranges in compressive strength.

TABLE 6.

Compressive Strength. Tons/sq. ft.	Number of Samples.
Under 20	12
20—30	16
30—50	2
50—110	5
100—150	5
Over 150	2

The variation in compressive strength values is due to variation in porosity, insoluble content and texture. The most resistant are fine or medium grained stones with low porosity and low percentage of insoluble material. Weak stones have high porosity values. Coarse grained stones are usually weaker than fine grained stones with the same porosity. A detailed account of the factors affecting compressive strength will be found on p. 33).

Table 7 gives the ranges in compressive strength of stones from various localities.

TABLE 7.

Locality.	Range in Compressive Strength. Tons/sq. ft.	Number of Samples.
A	20—36	6
G	9—27	12
D*	34—318	9
B	21—31	6

Of these samples, which originally came from Quarry No. 9, four were taken out of an old building, three were obtained from the sea-wall where they had been for over 60 years, and two were collected from the quarry in 1929.

V.—FACTORS AFFECTING THE PROPERTIES.

A.—FACTORS AFFECTING HARDNESS.

The "hardness" of a building stone (*i.e.*, the ease or difficulty with which is is dressed to any required shape and size) depends largely upon two factors, the hardness of the component minerals and their state of aggregation. Merrill (1910, p. 33) states that "however hard the minerals of a rock may be, it appears soft and works readily if the particles adhere with slight tenacity. Many of the softest sandstones are composed of the hard mineral quartz, but the grains fall apart so readily that the stone is as a whole soft."

Most samples of the coastal limestone are of similar composition, so that the first factor, the hardness of the component minerals, is relatively unimportant. The difference in "hardness" must therefore be due to state of aggregation. If the grains are closely packed together and are efficiently cemented, the stone will have a low porosity and will be fairly hard. If, on the other hand, the grains are loosely held together, the stone will have a high porosity and will be fairly soft. Porosity is therefore to some extent a measure of "hardness." To test the accuracy of this statement I arranged Coalstad's samples in the order of their "hardnesses" and found that the arrangement fitted in well with their porosities. 9398 having the lowest porosity was the hardest stone; 9392 having the highest porosity was the softest. Here, then, are the answers to the questions (a) and (b) asked on p. 18. 9398 is harder than the other samples because it has the lowest porosity. Difference in porosity is not associated with difference in mineral composition, but is due to difference in the state of aggregation.

The state of aggregation is therefore the primary factor affecting the "hardness," and to account for differences in "hardness" and porosity, a detailed petrographic examination of the internal structure of the stone is necessary. This examination has been made and the types described in the petrological section of this paper. The diversity of these types is responsible for the wide range in porosity and "hardness." Thus we have fine, medium and coarse grained stones, some of which have their grains closely packed together whilst others have their grains comparatively widely separated. The cementing of the grains may be due to thin films of carbonate which coat each shell fragment, or thick patchy cement which binds some grains and not others; or again the cement may be plentiful but quite porous as in 9400 and 9401 (p. 27).

Porosity is to a large extent a measure of the "hardness," but some stones which are identical in porosity, composition and grain size, differ in degree of "hardness." This is particularly noticeable in average samples of stone from localities B and C. The locality B stone is much harder than the stone from locality C, to which it is similar in many respects. Petrographic examination has revealed a very important difference in the nature of the cement. The cement in both is not a homogeneous filling, but is granular (i.e., composed of very fine grains of calcium carbonate closely bound together), but that of the B stone is much coarser and appears to be more crystalline than the cement in the C stone. The result is that the coarsely granular cement of the B stone has a greater binding power than the finely granular cement of the C stone which tends to decompose into gritty material and chalky powder. The difference in "hardness" of the two types of cement is probably due to the same factors which are responsible for the difference in

"hardness" of two stones of similar composition such as chalk and marble. The chalk is soft and powdery, and is made up of finely divided calcium carbonate, whilst the marble is hard and coarsely crystalline.

It is therefore possible to obtain a stone with a high porosity (say 46 per cent.) which is comparatively hard; and it is from the juvenile type of quarry (*i.e.*, where there is no network between the cap and bedded stones) that such a stone is usually obtained; on the other hand a softer stone with a lower porosity is usually obtained from the mature type of quarry.

B—FACTORS AFFECTING COMPRESSIVE STRENGTH.

The principal factors affecting the compressive strength are porosity, insoluble content and grain size. Stones with low porosity and insoluble content and fine or medium grain give high compressive strength values: stones with high porosity and insoluble content and coarse grain give low compressive strength values.

Table 8 shows the compressive strength, porosity and insoluble content of stone from various localities.

TABLE 8.

Sample.	Locality.	Quarry.	Compressive Strength.	Porosity.	Insoluble Content.
			Tons sq. ft.		
9398	D	No. 9	150 276 318	23·6	19·67
9397	D	No. 9	129 143	25·6	16·25
9395	D	No. 9	112 79	29·8	25·44
9403	Taken out of an old building		70 65	32·8	30·31
9399	B	No. 5	111 59	37·4	14·37
9396	D	No. 9	52 34	41·2	18·15
9401	Taken out of an old building		41 23	35·2	66·81
Average sample	A	Nos. 1 and 2	27 average	41·0 average	38·00 average
Average sample	B.	No. 3	26 average	46·0 average	16·60 average
9402	Taken out of an old building		14 12	49·7	18·67
9400	do.	do.	*12	36·5	61·20

* This sample had an initial fracture and was not square.

From the above figures it is possible to draw up a table (Table 9) from which, given two of the three values, the third may be determined approximately.

Table 9.

Type.	Porosity (volume of air space).	Insoluble Content.	Compressive Strength.	Examples.	Quarry.
	per cent.	per cent.	tons/sq. ft.		
A1	Under 25	Under 20	Over 150	9398	No. 9 (loc. D)
A2	25—30	Under 25	100—150	9395 9397	No. 9 (loc. D)
A3	25—30	Under 30	75—100	9395	No. 9 (loc. D)
A4	30—40	Under 30	50—75	9399	No. 5 (loc. B)
A5	30—40	Over 30		Average stone do.	No. 3 (loc. B) Nos. 1 and 2 (loc. A)
	Over 40	Under 30	Under 50	9396	No. 9 (loc. C)
	Over 40	Over 30		9401 9400 9402	Taken out of an old building

Unfortunately this table is not as useful as it may seem, because most of the stones used for building purposes belong to the type A5; but it serves to indicate that the compressive strength varies with porosity, insoluble content and grain size. It is possible, however, having obtained the porosity values and insoluble contents of stones of this type (type A5), to arrange them roughly in order of their compressive strengths, taking into account grain size and the nature of the cement, as well as porosity and insoluble content; and it is further possible to estimate roughly the compressive strength of each stone by comparing it with a stone which possesses similar characters and properties and whose compressive strength is already known.

C—Factors Affecting the Acoustic Properties.

Until recently the use of coastal limestone was restricted to exterior facings and foundations of buildings, but as sound-absorption tests showed that the Coogee stone possessed fairly good acoustic properties, the University authorities decided to line the Winthrop Hall with this stone.

In a large hall such as the Winthrop Hall, it is essential that the lining material should be a good absorber.

Sound incident on a material is reflected, absorbed and transmitted [as indicated in Fig. 8]. When such a material is installed on the walls of a room, its absorbing effect includes the transmitted sound as well as the pure absorption in the material. In this sense an open window is considered a "perfect" absorber, but it is really a perfect transmitter. The coefficients determined are based on this conception; that is, that what is not reflected is "absorbed."

The open window is taken as the standard absorber with a coefficient of 1·00 or 100% absorption. A material in the room with a coefficient of 0.50 means that it absorbs 50% as much sound as an open window of equal area.—(Watson, 1927, p. 5.)

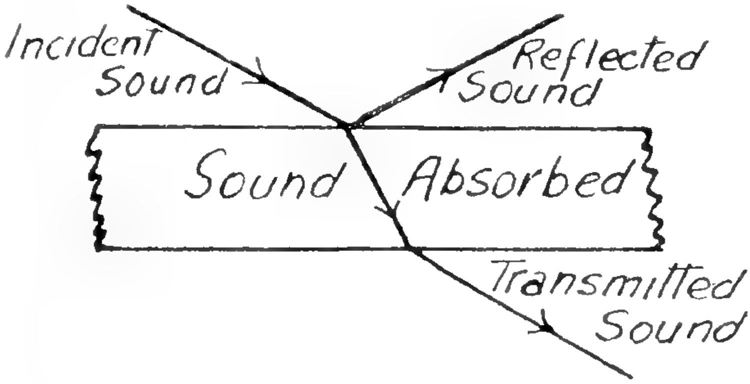

Fig. 8.—Reflection, Absorption and Transmision of Sound.

Absorption of sound by materials is due to porosity, compressibility and elasticity. In building stones porosity is the main factor; in carpets, compressibility; in thin glass, elasticity. Perhaps the most important feature in a building stone of the coastal limestone type is the open nature of the pore spaces. The porosity experiments show that all pore spaces in the stone are in direct communication with the atmosphere, and it is probably on this account that the stone has such a high absorption coefficient.

Table 10 gives the absorption coefficient of various materials, including the Coogee (Hackett) stone.

TABLE 10.

Sound Absorbing Coefficients. Pitch 512.

Material.	Coefficients. per sq. ft.
Open window	1·000
Ventilators	0·750
Coogee stone	0·220
Plaster on wood lath	0·034
Brick wall	0·032
Linoleum	0·030
Glass (single thickness)	0·027
Plaster on tile	0·025
Marble	0·010

Although the Coogee stone is the only stone that has been tested, there should be no doubt that most of the coastal limestone would give high absorption coefficients on account of the open character of the pore system, and it is quite possible that some stones would give better results than the Coogee stone

VI.—WEATHERING OF LIMESTONE.*

A—AGENCIES OF WEATHERING.

The weathering of limestone is brought about by chemical and mechanical agencies.

1. *Chemical.*

Ordinary rain water contains a small amount of carbon di-oxide (CO_2) that it has received from the atmosphere, and is thus a very dilute solution of a weak acid known as carbonic acid (H_2CO_3), which dissolves limestone.

$$H_2CO_3 + CaCO_3 \rightleftarrows Ca(HCO_3)_2$$

* For detailed accounts of the weathering of building stones, see Howe, 1910, chap. IX., and Merrill, 1910, p. 418.

When other agencies are excluded, the solvent action of carbon di-oxide bearing water is very slow. Hirschwald (1908) experimented on thin slices of limestone exposed to the atmosphere for a definite period and showed that about .00085 mm. of surface was removed per year from the limestone slices.

The effect of rain water by itself is therefore quite small, but in towns, through the continual combustion of coal, sulphuric acid is liberated in the atmosphere, and this acid has a greater chemical effect on limestone than carbonic acid.

$$H_2SO_4 + CaCO_3 + H_2O \longrightarrow CaSO_4 + 2H_2O + CO_2$$

The addition of sodium chloride to a CO_2-bearing solution increases its solvent action on the carbonate. This reaction is frequently encountered near the coast where the atmosphere contains a large percentage of salts.

Coastal limestone that has been in buildings for years is nearly always coated with vegetable organisms such as microscopic algae, lichens and mosses, and decay by organic acids excreted by these organisms, is considered by some writers to be an important chemical effect. Other writers consider that the chemical effect is not great, and that the coating of organic matter protects the stone from the sun's rays and the rain.

2. *Mechanical.*

The principal mechanical agencies of decay are wind, changes of temperature and frost.

Wind is a powerful agent in hastening the decay of buildings near sea beaches, for wind-blown sand is an effective abrasive in wearing away loosely coherent stones. In addition the effect of a strong wind in driving rain into the interior of porous stones is noteworthy.

The destructive effect of variation in temperature is very important in desert regions where cold nights follow hot days; and the effect is more marked in close than in open-grained stones. The open grain and high porosity of the coastal limestone are therefore desirable features in a stone which is to be subjected to a wide temperature range.

Frost action would probably produce very little, if any, effect on the coastal limestone for it contains a large amount of air space which would allow for the expansion of water when converting to ice. Moreover, heavy frosts are unknown on the Swan Coastal Plain where the limestone is solely used.

Alternate water-logging and drying-out, though injurious to certain types of building stone, appears to have little effect on the coastal limestone.

The destructive effect of insects, such as ants, has not been mentioned, as far as I know, in text-books on building stones, but I have seen, on several occasions, very crumbly coastal limestone foundations of houses, harbouring ants. In this instance open grain is detrimental to the value of a stone for foundation work.

B.—RESISTANCE OF THE COASTAL LIMESTONE TO WEATHERING.

During the porosity determination the coastal limestone was subjected to very drastic treatment which consisted chiefly of periodic temperature changes over a wide range on totally dry and on completely waterlogged stones; and consequently a certain amount of material was detached from each block. By weighing the block before and after the experiment the total loss of detachable material was determined, and I think that the percentage loss of detachable material calculated for each stone should give some comparative idea of its resistance to weathering.

The method adopted for the porosity is outlined on p. 28, but to save reference the principal stages are outlined below (Table 11), together with the nature of the changes which occurred and the possible sources of loss of detachable material.

TABLE 11.

Stage.	Nature of Change.	Source of Loss.
1. Drying at 130°C. for 4 hours	Rapid temp. change from room temp. to 130°C.	Expansion
2. Cooling in desiccator	Rapid temp. change from 130°C. to room temp.	Contraction
3. Weighing ...	... ...	Handling
4. Boiling	Rapid temp. change from room temp. to 100°C.	Expansion and agitation of block due to convection currents
5. Cooling	Slow temp. change from 100°C. to room temp.	Contraction
6. Repetition (twice) of 4 and 5	Repetition (twice) of 4 and 5	Repetition (twice) of 4 and 5
7. Weighing	... ...	Handling
8. Redrying at 130°C. for 4 hours	Rapid temp. change from room temp. to 130°C.	Expansion
9. Cooling in desiccator,	Temp. change from 130°C. to room temperature	Contraction
10. Weighing ...	... ...	Handling

The percentage loss of detachable material ranges from 0.00 per cent. up to 0.35 per cent., with an average value of 0.16 per cent. Out of thirty-three samples of stone, ten gave values under 0.10 per cent.; thirteen gave values between 0.10 per cent and 0.20 per cent; five between 0.20 per cent. and 0.30 per cent.: and five over 0.30 per cent. Taken individually the value for each stone has no significance, but collectively the values afford a ready means of comparison; and in Table 12 are given the ranges in percentage loss of detachable material for stone from various localities, the average values and the numbers of samples tested.

TABLE 12.

Locality.	Range in Percentage Loss of Detachable Material.	Average Percentage Loss of detachable Material.	No. of Samples Tested.
B (three quarries) ...	0·00—0·16	0·08	7
D (two quarries) ...	0·05—0·33	0·12	7
A (two quarries) ...	0·10—0·19	0·15	4
C (two quarries) ...	0·11—0·35	0·22	4
E (two quarries) ...	0·18—0·31	0·25	6

There is no relationship, as far as I can see, existing between the percentage loss of detachable material and porosity, insoluble content, character of the cement or texture, but it is significant to note that in general, the samples obtained from quarries containing stone of variable quality, invariably lose a fairly large amount of material during the porosity determinations. It is also significant that most of the stone from the localities C and E has a porosity of over 50 per cent. and an average percentage loss of detachable material of over 0.20 per cent.

It is reasonable to assume that, in general, highly porous stone of a variable quality should weather more easily than stone of even quality and low porosity, for I consider that to some extent the amount of material lost during the porosity determinations does give an indication of the resisting power of a stone to weathering. Furthermore, the average values given in Table 12 accord fairly well with my field and laboratory observations concerning the quality of the stones and their weather-resisting powers. Such observations are of a general character and are based not on individual samples but on a number of samples and on the nature of the particular quarry from which they were obtained.

The examination of stones taken from the walls and foundations of old buildings (*e.g.*, 9395, 9396, and 9400 to 9403), and also of a stone (9398) taken from the sea-wall at North Fremantle, where it had been for over 60 years, shows that they have stood the test of time remarkably well. 9398, originally from quarry No. 9, loc. D, is very similar to 9397, which was collected from the same quarry in 1929. It is interesting to note that 9398 gave exceptionally high compressive strength values the highest (as far as I know) yet obtained for the coastal limestone. Of the stones taken from old buildings, 9395 and 9396 (originally from the same quarry as 9397 and 9398), and 9402 and 9403 (quarry not known), compare favourably with similar types of stone recently collected from the various quarries. 9400 and 9401 are exceptional (being the only representatives of Textual Type 3), and cannot be compared with other stones.

C—INDURATION OF STONE ON EXPOSURE.

That the coastal limestone hardens on being removed from the quarry, or when exposed in an old quarry face, is well known to contractors and stone-masons. The reason for this is that the stone holds a certain amount of water containing lime carbonate in solution or suspension, and when this "quarry water" is drawn to the surface of the stone by capillarity, and evaporation takes place, the lime carbonate is deposited on the surface of the stone as a thin film, which helps to bind the grains more closely together, and prevents to some extent the entrance of rain water into the stone. The crust so formed is necessarily very thin and, according to Merrill (1910, p. 432), when once it is destroyed it can never be replaced. Shaping of the stone, according to him, should therefore be done before it is put into place and while it still contains the quarry water. If the shaping is done after the stone is set in position, the thin crust of lime carbonate will probably be removed and the stone will be less resistant to weathering than it would be if the crust were not removed.

Old cuttings or quarry faces frequently show the indurated crust, and one of the best examples is an old cutting, Quarry No. 11, locality E.

Merrill states that the indurated crust can never be replaced, but from observations over a period of three years, on a block of stone from the above-mentioned quarry (No. 11, loc. E), I think that the coastal limestone develops a hardened surface in summer which it partly loses in winter. Of course it must be remembered that this limestone is an exceptional type of building stone, particularly so because of its high porosity.

VII.—ORIGIN OF THE COASTAL LIMESTONE.

It is believed by most local geologists that much of the coastal limestone is of dune origin, but no detailed investigations have been made to prove whether this is or is not so. However, although this paper is entirely concerned with the economic aspect of the stone, it is worth while to record briefly, certain observations obtained from field and laboratory investigations, which may explain the processes by which the various types of stone have been produced.

There are, between Balcatta and Coogee, numerous quarries, any one of which may belong to one of two types—juvenile or mature. The characteristics of these types are given on p. 19. The terms "juvenile" and "mature," which I have borrowed from physiography, denote two extreme stages in the development of the bedded stone and the network evidently derived from it. Intermediate stages can be observed in several quarries. For example, in the juvenile quarry, No. 7, locality C, there are in places small networks. However, the characteristics are predominately those of a juvenile quarry, and the quarry is consequently classified as juvenile. Conversely in a mature quarry there may be patches which are juvenile in character, but they are relatively insignificant, and the quarry is therefore considered as being mature. The amount of network in a quarry is the criterion by which the quarry is classified.

Large pipes (or trunks) may be present in both types of quarry irrespective of whether network is or is not present. In quarry No. 4, locality B, for example, there are numerous large pipes which appear to be downward extensions of the capstone, but no network is present. On the other hand, both network and pipes can be seen in quarry No. 8, locality D.

From the petrographic examination of a large number of stones one fact is fairly obvious—that is, the cementing material is of secondary origin. This suggests that the limestone was originally a current bedded deposit of loose sand—probably beach sand.

It is now possible to trace the history of the various materials (*i.e.*, capstone, pipes, network and bedded stone) constituting the limestone. My interpretation is as follows:—

The material which originally gave rise to the coastal limestone was in the form of a sand dune. If it were possible to cut a section through the dune it would be seen that the material was loose beach sand (composed of quartz grains and shell fragments) and that it was current bedded. Near

the surface of the dune there would be a fairly large amount of vegetable matter in the form of matted roots, which represented either living plants or ones which had been buried in the sand.

Rain falling on such a dune would eventually effect the cementation of the closely packed grains. The presence of salts and weak acids in the rain water would cause the shell fragments to dissolve slightly, and on removal of the water, thin films of chemically precipitated carbonate would be left on their surfaces. (There are numerous examples of stones of this type, particularly ones containing only very small percentages of insoluble material.) Some of the dissolved carbonate would probably be removed in solution and redeposited close-by (on the frosted surfaces of quartz grains) or carried downwards by gravity or upwards by capillarity (thus accounting for the capstone), the depth from the surface and the climatic conditions governing to some extent the upward movement due to capillarity.

This represents the juvenile stage in the development of the limestone.

Finally, by the continual dissolving of the shell grains and redeposition of carbonate elsewhere, the mature stage would be reached. The bedded stone some distance below the surface would be probably no different from similarly situated stone at the juvenile stage of development, but near the surface certain changes would be noticed. Around the organic matter present in the surficial layers calcium carbonate would be precipitated, and by the passage of circulating solutions, downward by gravity and upwards by capillarity, a network would be formed, consisting of tubes of calcium carbonate and interstitial loose material. The bedded stone just below the network would be extremely porous, and the small delicate shells such as foraminifera would completely lose their identity.

Petrographic observations on stones collected from different depths in juvenile and mature quarries support the ideas mentioned above. In the juvenile quarry the quality of the stone is fairly uniform throughout, irrespective of the depth from which the samples are obtained. On the other hand in the mature quarry porosity values as high as 55 per cent. are obtained from stone just below the network, while stone some distance below the network may give values under 40 per cent.

Stone of uniform quality may be obtained from both types of quarry, but in the mature type it is necessary to select the stone carefully, on account of the network and the highly porous bedded stone immediately underlying it. In the juvenile type there is less need of careful selection for most of the stone is uniform in quality and it is only necessary to discard the bedded stone containing organic matter, which, in the few quarries I have seen, is only a few feet in thickness.

Concerning the origin of the large pipes, or trunks, I feel hesitant in expressing an opinion, for I have not seen very many of them and have not studied them in detail. In quarry No. 4, locality B, there are several large pipes which appear to be downward continuations of the capstone. The fact that they are essentially vertical seems to suggest that their formation has been controlled by gravity, and that they have thus developed from the surface downwards. The stone from this quarry is extremely hard and it has a very low porosity.

VIII.—SUMMARY.

About forty samples of limestone suitable for building purposes were obtained from various quarries between Balcatta and Coogee on the Swan Coastal Plain, and were examined in the laboratory. The principal characters and properties of the stone are as follows:—

Colour—Pale ash-grey, white, cream, buff.

Constituents—Quartz grains and carbonate grains (many of which are definite shells or shell fragments) cemented by calcium carbonate. The cement is believed to have been derived from the carbonate grains by the process of solution and redeposition. The amount of acid insoluble material in the stone varies from 5 per cent. to 66 per cent. This variation is influenced by the grain size, for in most of the medium and coarse grained stones the largest grains are of quartz.

Texture—The stones vary considerably in grain size. There are fine, medium and coarse grained stones with average grain sizes of 0.2 mm., 0.5 mm. and 1.0 mm. respectively. In some stones the grains are packed closely together; in others they are fairly widely separated. The cement varies in quantity and distribution. In some stones it occurs as thin films surrounding the carbonate grains from which it has been derived; in other stones it is very patchy, being particularly thick around quartz grains. The cement never completely fills the spaces between the grains, and consequently the stone is characterised by a high porosity. The wide range in porosity, 17 per cent. to 57 per cent. (average about 40 per cent.), is due to texture and is entirely independent of mineral composition.

Compressive Strength—The compressive strength depends largely on the porosity, insoluble content and grain size, porosity being the principal factor. Values obtained vary from less than 10 tons per square foot up to 318 tons per square foot, but most of the stones commonly used (those with porosity values exceeding 40 per cent.) give values less than 50 tons per square foot.

The coastal limestone includes, in addition to the bedded stone used for building purposes, several materials which have been referred to as capstone, large pipes and network. Quarries free of network are called juvenile quarries, while those containing a large amount of network are referred to as mature quarries.

Most, if not all, of the coastal limestone is considered to be of dune origin and is regarded as belonging to the Recent Period of the Cainozoic Era.

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TABLE 13.

Locality.	Quarry.	Catalogue Number.	Porosity (percentage volume of air space).	Bulk Density.	Weight (lbs./cubic foot). Maximum (water-logged).	Weight (lbs./cubic foot). Minimum (dry).	Density of Rock Material. §	Compressive Strength. (tons/sq. ft.)	Insoluble Content (percentage by weight).	Percentage Loss of Detachable Material during Porosity Determination.	Textural Type.	Compressive Strength Type.	Degree of "Hardness."
A.	1	9223 (a)	41·0	1·59	125·0	99·4	2·70	average 26·7	32·70	0·17	2b	A5	Medium
		9223 (b)	42·5	1·56	124·0	97·5	2·71		31·14	0·19	2b	A5	do.
	2	9389	41·8	1·56	123·6	97·5	2·69	average 28·6	49·63	0·10	2b	A5	Medium
		9390	43·7	1·51	121·7	94·4	2·69		38·09	0·14	2b	A5	do.
B.	3	9391	40·2	1·63	127·0	101·9	2·72	average 26·5	15·06	0·06	1b	A5	Medium
		9392	48·5	1·39	117·2	86·9	2·70		16·80	0·02	1b	A5	do.
		A'age of several samples	46·0	1·43	118·1	89·4	—		16·00	—	1b	A5	do.
	4	9227	17·9	2·24	152·4	140·0	2·72	Estimated at over 150 ...	8·12	0·00	1a	A1	Very hard
		9226	31·6	1·86	136·0	116·3	2·72	Estimated between 100—150	11·54	0·16	1a	A2	do.
		9225	35·0	1·77	132·5	110·6	2·72	Estimated 50—75 ...	15·62	0·10	1a—b	A4	Hard
		9224	39·7	1·63	126·7	101·9	2·71	Estimated 30—75 ...	14·62	0·11	1a—b	A4	do.
	5	9399	37·4	1·69	129·0	105·6	2·73	59—111 ...	14·37	0·04	1a—b	A4	Hard
C.	6	9235	55·3	1·22	110·8	76·3	2·72	Estimated at under 20 ...	11·98	0·35	1b	A5	Very soft
		9236	50·9	1·33	114·9	83·1	2·71	„ „ 20 ...	16·45	—	1b	A5	do.
	7	9237	39·2	1·65	127·5	103·1	2·72	Estimated 25—50 ...	24·20	0·13	1a	A4—5	Soft—medium
		9238	43·6	1·53	122·9	95·6	2·72	Estimated under 30 ...	28·65	0·11	1b	A5	Soft
		9239	56·8	1·17	108·6	73·1	2·72	„ „ 20 ...	15·93	0·27	1b	A5	Very soft
D.	8	9385	51·0	1·32	114·4	82·5	2·70	Estimated under 20 ...	28·76	0·07	1b	A5	Soft
		9386	47·0	1·43	118·7	89·4	2·69	„ „ 30 ...	31·62	0·05	1b	A5	Soft—medium
		9387	45·7	1·46	119·8	91·3	2·69	„ „ 30 ...	33·44	—	1b	A5	do. do.
		9388	41·4	1·57	124·0	98·1	2·68	„ „ 40 ...	28·57	0·05	1b	A5	do. do.
	9	9395†	29·8	1·88	136·1	117·5	2·68	79 413 ...	25·44	0·33	2a	A2—3	Hard
		9396†	41·2	1·59	125·1	99·4	2·70	34— 52 ...	18·15	0·05	2b	A5	Soft—medium
		9397	25·6	2·03	142·9	126·9	2·72	129—143 ...	16·25	0·12	2a	A2	Hard—very hard
		9398‡	23·6	2·08	144·8	130·0	2·72	150—318 ...	19·67	0·18	2a	A1	Very hard
E.	10	9228	34·8	1·77	132·4	110·6	2·71	Estimated 50—75 ...	10·81	0·24	1b	A4	Medium
		9229	53·2	1·26	112·0	78·8	2·70	Estimated under 30 ...	7·85	0·22	2b	A5	Soft
		9230	54·7	1·22	110·4	76·3	2·70	„ „ 30 ...	8·42	0·18	1b	A5	do.
	11	9231	45·1	1·48	120·7	92·5	2·70	Estimated under 50 ...	21·08	0·31	1b	A5	Medium
		9232	38·8	1·66	128·0	103·8	2·70	„ 50—75 ...	17·04	0·27	1b	A4	do.
		9233	40·8	1·60	125·5	100·0	2·70	„ under 50 ...	24·34	0·28	2b	A5	Soft—medium
F	12	10486	39·5	1·63	127·0	102·0	—	Estimated under 50 ...	24·12	—	—	—	—
Taken out of the wall of an old building	...	9400	36·5	1·69	128·4	105·6	2·66	11·7*	61·20	0·31	3	A5	Soft
		9401	35·2	1·73	130·1	108·1	2·67	23—41	66·81	0·16	3	A5	Medium, crumbly
		9402	49·7	1·36	116·0	85·0	2·69	12—14	18·67	0·34	1b	A5	Soft
		9403	32·8	1·80	133·0	112·5	2·68	65—70	30·31	0·17	2a	A4	Medium—hard
Garden Island ...	...	9393	25·1	2·03	142·6	126·9	2·73	Estimated over 150 ...	4·57	—	1—2a	A1	Very hard
Hamelin Bay ...	...	8825	35·1	1·77	132·5	110·6	2·73	Estimated 50—100 ...	Not determined, estimated under 2 per cent.	0·11	2a	A3—4	Hard

* This sample had an initial fracture and was not square. † Taken out of the wall of an old building, but were originally obtained from quarry No. 9. ‡ Taken from the sea-wall at North Fremantle, where it had been for 60 years (originally from quarry No. 9). § Calculated from porosity data : inserted here only as a check on the porosity determinations.

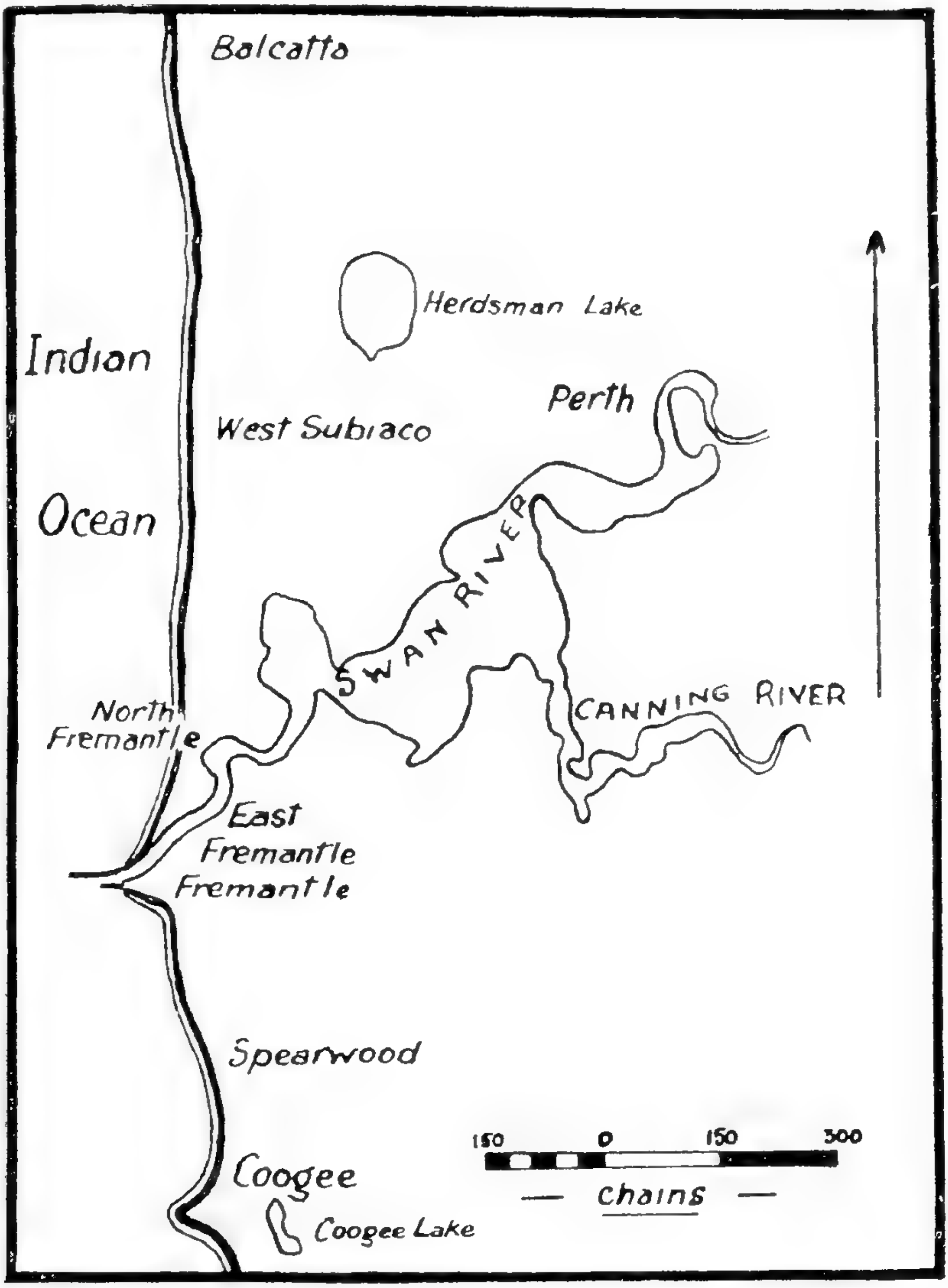
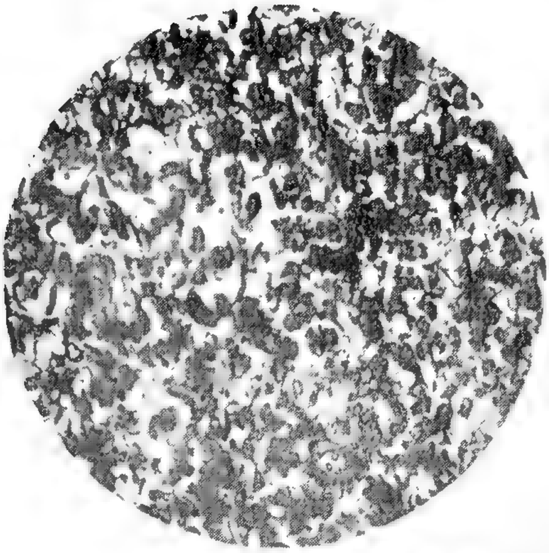

Balcatta
Herdsman Lake
Indian
Ocean
West Subiaco
Perth
SWAN RIVER
CANNING RIVER
North Fremantle
East Fremantle
Fremantle
Spearwood
Coogee
Coogee Lake
150 0 150 300
Chains

Plate I.



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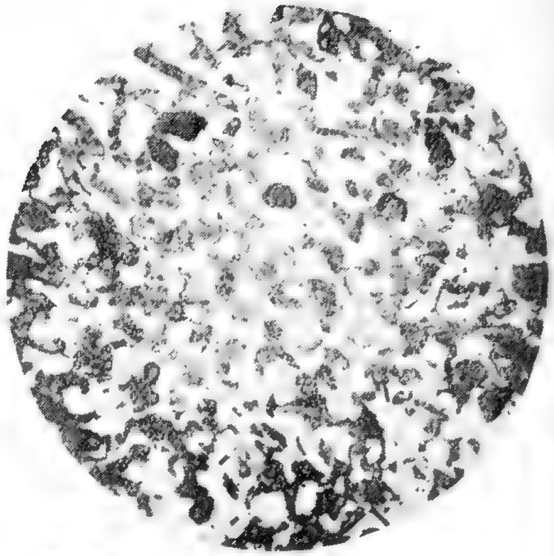

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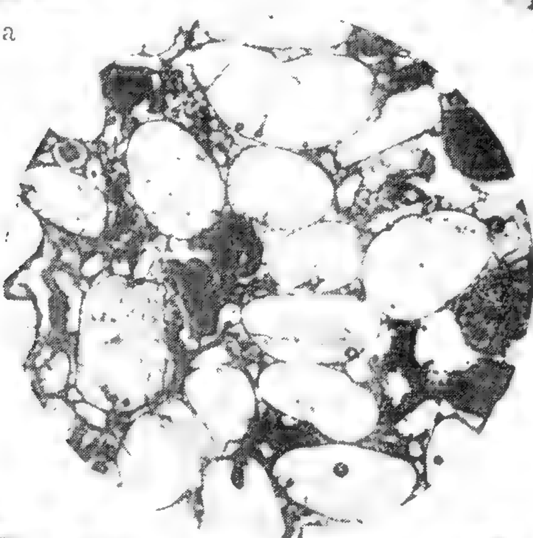

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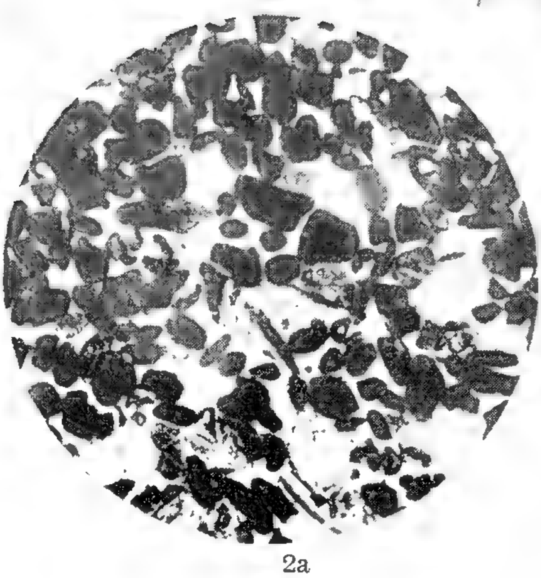

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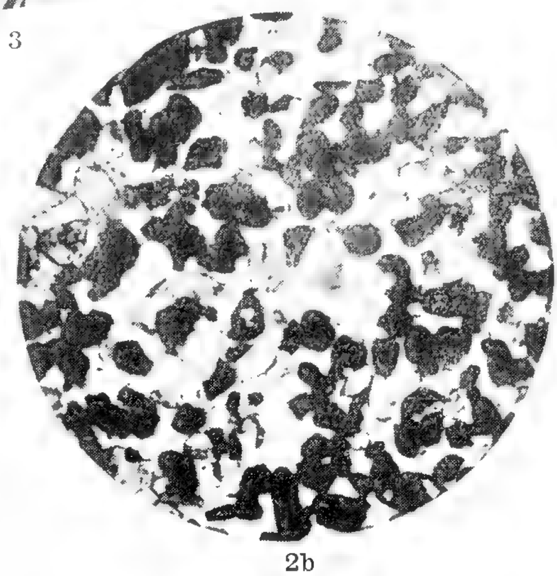


2b

× 12

PLATE II.

Photomicrographs illustrating Textural Types.

1a, 9237 Quarry No. 7, locality C.—Black portions represent carbonate grains. Quartz grains and air-spaces appear colourless.

1b, 9235 Quarry No. 6, locality C.—Black and dark grey portions represent carbonate grains; quartz grains are light grey and colourless; air-spaces are colourless.

2a, 9398 Quarry No. 9, locality D } The constituents and air spaces have the same
2b, 9223 Quarry No. 1, locality A } colouring as in 1b.

3, 9400 Taken out of an old building. Colourless grains are quartz; black grains are carbonate. The cement embedding the grains is porous, the black patches representing cement and the colourless patches air-spaces.

Photo. H. Smith.

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

3.—CONTRIBUTIONS TO THE MINERALOGY OF WESTERN AUSTRALIA.

SERIES VIII.

By EDWARD S. SIMPSON, D.Sc., B.E., F.A.C.I.

Read: 15th November, 1933. Published: 14th May, 1934.

(With two figures.)

CONTENTS.

(1) ANTIMONY OCHRE, WILUNA, CEN.

The most important bodies of gold ore at Wiluna are N. and S. shear zones in carbonated and chloritised Precambrian dolerite. These are practically free from antimony minerals, the only abundant sulphides in them being arsenopyrite and pyrite. Crossing the lodes more or less at right angles are a number of small quartz reefs of later age which are also auriferous, and often highly so. These, below water level, carry bunches of stibnite, and, nearer the surface, corresponding masses of "antimony ochre" derived from its weathering.

This "ochre" is microgranular, dense and hard, and intimately intergrown with granular quartz. In colour it is usually dull or bright yellow, but not uncommonly grey, and occasionally almost white. Sometimes the whole mass, which may reach many pounds in weight, is of almost uniform colour and texture. Quite often it is distinctly banded in concentric lines representing interrupted stages of oxidation, with at times a central core of unaltered stibnite.

In the Moonlight gold mine (G.M.L. 870), stibnite and dense antimony ochre are particularly plentiful in one of these quartz veins. On the old mine dump, when inspected by the Writer in 1932, many beautiful examples were to be seen of the rhythmical oxidation of stibnite to stibiconite and other oxidised products. The accompanying Fig. shows one such with a small patch of residual stibnite at the top near the right side, the balance of the specimen being an intimate mixture of quartz and antimony oxides, banded in different shades of yellow and grey. For the excellent photograph of this specimen I am indebted to the kindness of Mr. H. J. Smith of the Geology Department of the University.

To shed some light on the composition of the oxides, an analysis was made of a specimen showing no banding but only a slight blotchiness in

colour. It was very hard and dense in texture. Specific gravities of various chips ranged from 3.8 to 4.0, indicating an uneven distribution of quartz.

The analytical results were:

ANTIMONY OCHRE, WILUNA.

Sb_2O_4	Fe_2O_3	Al_2O_3	CaO	MgO	H_2O +	H_2O −
61·79	·25	·50	3·51	·19	2·15	·45

SO_3 Water sol.	SO_3 Acid sol.	CO_2	SiO_2	Total.
·14	nil	nil	30·25	99·23*

Analyst: C. R. LeMesurier.

ANTIMONY OCHRE, WILUNA.
Showing rhythmical weathering of stibnite.
Scale of Nature. *Photo., H. J. Smith.*
Fig. 1.

* Add 0·48 per cent. extra oxygen if CaO is present as atopite.

Rejecting (1) the silica which, except for a little kaolin, was proved to be present as quartz, (2) the water soluble SO_3, and an equivalent amount of CaO and H_2O, together present as gypsum, and (3) the Fe_2O_3, Al_2O_3, etc., existing as kaolin and limonite, one is at once struck with the appreciable remnant of lime which may be present as atopite.* It is evident that both stibiconite and cervantite are present, the approximate proportions being—

Stibiconite, $Sb_2O_4.H_2O$	55·2 per cent.
Cervantite, Sb_2O_4	25·3 ,,
Atopite, $Ca_2Sb_2O_7$?	19·5 ,,
	100·0 per cent.

E. S. Larsen in 1921† noted, optically, the complexity of an antimony ochre labelled "cervantite" from Western Australia, possibly from Wiluna. In the banded specimens stibiconite and cervantite appear to form alternating layers.

APATITE, BARITE AND GLAUCONITE, GANTHEAUME BAY, MUR.

Towards the end of 1932 the writer had occasion to visit the lower reaches of the Murchison River, where for about fifty miles it flows through a deep gorge before reaching the sea in Gantheaume Bay. The walls on the south side of this gorge are about 800 ft. high and consist essentially of reddish standstone (Jurassic?). The north side is somewhat higher, the sandstone being overlaid by glauconitic sands and shales, and finally capped by chalk, both of proved Cretaceous age.‡ As at Gingin and Dandaragan, 250 miles to the south, apatised wood and coprolites occur at the junction of the chalk and glauconitic material, whilst barite was found in the latter associated with gypsum.

Apatite.—Amongst the talus of Thirindine Bluff, ten miles north-east of the mouth of the river, a large number of specimens of fossil wood up to 7 or 8 lbs. (3 or 4 kilos) in weight have been found, the petrifying medium being mainly fluorapatite, a partial analysis showing P_2O_5, 30.60 per cent; F, 2.74 per cent., equal to 72.6 per cent. of $Ca_5F(PO_4)_3$. Outwardly they resemble the apatised wood (Cedroxylon), which is so plentiful at Dandaragan, but rare at Gingin, on precisely the same horizon.§ The Gantheaume Bay specimens are all fragments of stems or limbs, in which the annual growth rings are plainly visible to the unaided eye. Occasional "knots" are seen, where branches have once grown, and holes made by boring organisms are very common, as at the two southern localities. These holes, averaging 0.25 to 0.5 inch (6 to 12 mm.) in diameter, are usually filled with a firm granular mixture of apatite, chalk and glauconite.

Examination of cross, tangential and radial sections under the microscope shows that the cell structure is beautifully preserved. In cross section the tracheids are thin walled and partly air filled, partly filled with dense apatite. In radial section, rows of pits can be seen in the walls of

* Cf. Natta and Baccaredda; Z. Kr. 85, p. 271 (1933); Minl. Abs. 5, p. 294 (1933).
† Micr. Det. of Nonop. Minerals, p. 55.
‡ Mr. L. Glauert has recognised a number of typical fossils in both series.
§ E. S. Simpson, Jour. Nat. Hist. Sc. Soc. W.A. 4 (1912), pp. 33–37.

the tracheids, sometimes single, sometimes double. In the latter case the longitudinal spacing is not quite even, so that some pairs of pits are opposite, others alternate. Medullary rays are fairly numerous, and are composed of three to ten cells in a single series. The wood appears to be that of a conifer, similar in structure to the apatised wood at Dandaragan.

When the wood is crushed or ground down for section making, some pieces, if not all, emit a strong fetid odour, approaching that of a mixture of hydrogen phosphide and sulphide.

Associated with the apatised wood at Thirindine Bluff, there are a few coprolites, the largest one seen being 12 inches in length and 3 inches in diameter (30 x 7 cm.). At a second locality, White Cliff, overlooking the river only four miles from its mouth, these bodies are very plentiful. Here they are to be seen in position, associated with flints, in the lower portion of the chalk bed. They are spherical, oval or cylindrical in form, and vary in weight from a few ounces up to 2 or 3 lbs. Most of them are greyish black in colour on the surface, and pale yellowish grey on a fresh fracture. They are dense, hard and tough. Although easily separable from the soft chalk matrix, being in such a remote locality, there is little probability of any industrial use being made of them for the present.

The phosphoric oxide content was determined on three characteristic specimens, the results being 28.42, 28.84 and 29.10 per cent. Finally a complete analysis was made of one of them with the following results:—

COPROLITE, WHITE CLIFF, GANTHEAUME BAY.

CaO	MgO	FeO	MnO	P_2O_5	F	Cl	H_2O+	H_2O-
46·63	·48	traces	·04	29·10	2·44	·17	3·97	·90
SO_3	CO_2	Na_2O	K_2O	Al_2O_3	Fe_2O_3	SiO_2	Org	Total.
1·50	5·12	·66	·46	·53	1·93	5·53	1·60	101·06
							Less $O = F_2 + Cl_2$	1·07
							Net Total	99·99

Analyst: C. R. Le Mesurier.

The usual humus factor 1.724 was used in calculating the organic matter from the carbon determined by wet combustion. Of the SO_3, 0.20 per cent. was water soluble, 1.30 per cent. soluble in HCl.

Calculation from these figures, using the microscope section as a guide, indicates that the coprolite consists, to the extent of about 78 per cent, of fluorapatite with a ratio F:OH equal to 17:1. In addition the following minerals are intimately intergrown with it: calcite, glauconite, gypsum, a basic ferric sulphate (natrojarosite?), quartz, kaolin and organic matter.

Although CO_2 is present in the coprolite there is no evidence whatever of any "carbonato-phosphate," nor "oxyphosphate" such as is postulated by some authors who either fail to look for fluorine, or to determine it accurately.

Barite.—A few concretionary masses of dense barite with an oolitic surface were found associated with gypsum in a Lower Cretaceous shale underlying the chalk at "White Cliff." The specific gravity in mass is 4.17, and the usual chemical reactions have been observed. The barium of the nodules is probably derived from the chalk, and the sulphate ion from the oxidising marcasite or pyrite concretions which are common in the shale.

Glauconite.—In addition to the glauconite already mentioned as occurring throughout the coprolites, and as a constituent of the filling of worm holes in the fossil wood, the mineral is abundant in the sandy and clayey beds underlying the chalk.

At White Cliff there are banks of dark green (Ridg. 25'''l) sand, which appears under the microscope to contain about 80 per cent. of dark olive green to olive brown, translucent, glauconite. This is in subangular, mammilated and rounded granules, some of which are clearly internal casts of foraminifera. Their diameter ranges from 0.02 up to nearly one millimetre. All of them, even the smallest, are made up of a compact mass of minute, highly birefringent scales.

Under the chalk at Thirindine Bluff is a rusty white sand with an efforescence of sulphate. Microscopic examination of this reveals much quartz, with about 20 per cent. of olive brown glauconite. Much of it is in granules similar to those at White Cliff. Some, however, are deeply corroded, and all have a thin coating of rusty material. This is probably to be accounted for by the action of acid solutions resulting from the weathering of pyrite or marcasite concretions. This suggestion is supported by the low percentage of acid-soluble potash left in the sand, viz., 0.53 per cent., which is only equivalent to about 7.5 per cent. of unaltered glauconite, a figure far below that derived from microscopic examination, and by the sulphate efflorescence.

At the few spots where the chalk was examined closely, it appeared to be singularly devoid of glauconite granules.

NATIVE ARSENIC, KALGOORLIE, CEN.

Through the courtesy of Messrs. S. F. C. Cook and R. F. Playter, of Kalgoorlie, the writer has been able to examine a small specimen of native arsenic obtained from the 1,537ft. level in Chaffer's Gold Mine, at Boulder, Kalgoorlie. The specimen was found in a vugh in the Great Boulder main lode (which is identical with the Horseshoe No. 4 lode) at a point about 100 feet south of Chaffer's shaft. This lode is a silicified and carbonated shear zone is a chloritised quartz dolerite of Precambrian age. The vugh was lined with crystals of quartz and dolomite, on to which the arsenic had grown in the form of a mammilated mass about 25 mm. (1 inch) thick. It is thus the latest mineral to form in the lode. Internally, the mass was rather coarsely crystalline, with an obscurely radiated structure.

A freshly broken surface of the mineral has a greyish metallic lustre, which tarnishes in less than an hour to a rather dull black with faint iridescence. The clean mineral has a specific gravity of 5.85. A few small fragments were analysed. They showed 97.3 per cent. of arsenic, with appreciable quantities of vanadium, iron and oxygen. The mineral dissolves readily in warm dilute nitric acid.

The first record of native arsenic in Australia is that of W. F. Petterd, who in 1910 noted its presence in two tin mines at Mt. Bischoff, Tasmania.* In 1913 B. Dunstan recorded the mineral in Queensland, at Dargalong, with silver-lead ore, with gold at Charters Towers, Kilkivan, and Gympie, and also in a non-auriferous quartz reef at Gympie.† C. Anderson in 1916 gave

* Cat. of the Minerals of Tasmania, p. 13. † Queensland Mineral Index, p. 20.

Castlemaine, in Victoria, as a further locality, presumably in association with gold* Finally, in 1926, George Smith mentioned its occurrence in New South Wales in several parts of the Drake district, including Lunatic, as well as at Forbes, where it was observed in some of the richest gold ore.†

The mineral has never previously been observed in Western Australia, and it is noteworthy that it should have been found at a place where the gold ores in bulk contain only minute traces of arsenic, and that usually in the form of fahl ore, small crystals of arsenopyrite and realgar being very rare. Both arsenic and realgar appear to be two of the last minerals to be formed in the Kalgoorlie lodes.

(4) BERYL, MELVILLE, MUR.

From the information collected by the writer and others on the spot during the last two years, it would appear as if Melville were one of the most important localities for beryl in the State. Three varieties of the mineral have been recognised there, viz.:—

(1) Common beryl.

(2) Emerald.

(3) Rosterite (Caesium-beryl).

The area where it occurs covers a junction between Precambrian granite and amphibolite, and is remarkable for the ragged interpenetration of the two rock masses, and for the large number of quartz-felspar pegmatites traversing both. As a consequence of the chemical activity of the potash-bearing solutions accompanying the pegmatites, the amphibolite on one or both sides of the veins for a width of several feet is frequently converted into a biotite schist. The different varieties of beryl have been found within the amphibolite area, either in the pegmatite veins, or more rarely in the selvedge of biotite schist.

Common beryl.—This occurs only in the pegmatite veins, where it forms either large masses up to well over 50 lbs. (23 kilos) in weight, devoid of crystal outline, or else prismatic crystals from a fraction of an inch up to 16 inches in diameter (about 5mm. to 40 cm.). Larges masses capable of commercial development were noted at four points, viz., 20 chains N.E. of the "The Basin,"‡ 20 chains north of the first place, midway between Santa Claus M.L. 29 and Harrison's Reward M.L. 26, and lastly on the latter lease.

The large masses and crystals show no certain age relationships to the surrounding quartz and felspars, but the smaller crystals in the pegmatites are mostly completely embedded in quartz. In addition several were seen entirely embedded in a single microcline crystal, and two others in albite.

As regards form, *m* $(10\bar{1}0)$ by itself is very common, and a combination of *m* and *i* $(21\bar{3}0)$ fairly common. Three small crystals appeared to be a combination of *m* and *a* $(11\bar{2}0)$. In only one case were small faces of *s* $(11\bar{2}1)$ observed. The basal plane was not seen except as a parting, and in many cases even this parting was lacking.

* Bibliog. of Australian Mineralogy, p. 87, 96.

† Mineralogy of N.S.W., p. 9, 13.

‡ Local name for a circular hollow in the amphibolite hills, $2\frac{1}{2}$ miles N.N.W. of the town.

The colour of the common beryl is fairly variable. A series of tints between a green and a blue, roughly lying within Ridgways 39″ b-f and 41″ b-f, is widespread. These tints pass in patches, or in rare whole crystals, into a true sky blue or orient blue on the one hand, or into an emerald green (see below) on the other. Occasionally one notes a true green passing, in associated crystals, through yellowish green to greenish yellow (approximately 25′ i, 23′ k, 23′ i, 19′ i). Finally pale amber is a common colour in the larger masses and crystals, and one crystal was seen of a deep amber (near 16′ i). It is not uncommon to find amber and blue-green, or blue, crystals in the same pegmatite vein.

The translucency of all this "common beryl" is of an inferior order. It is quite common in a crystal to see a network of beryl of low translucency surrounding small "eyes" of almost transparent mineral. The lowered translucency is usually due to innumerable microscopic inclusions of gas or liquid.

Emerald. -True emerald of inferior quality was found just south of the place known as "The Basin." It occurred in a quartz-microcline-albite-topaz pegmatite, and more abundantly and of better quality in the biotite schist flanking it. For lack of capital the deposit has only been prospected on a very small scale, and so far without remunerative results.

The mineral is in prismatic crystals from 2 to 20 mm. (0.1 to 0.8 inch) in diameter. They range in colour from greenish white through many tints of green to deep emerald. The translucency varies greatly from crystal to crystal, and even within a single crystal small portions may be completely transparent, whilst other portions possess only a low translucency. Many of the crystals obtained have been very promising in colour and lustre, but none quite clear enough over a sufficient space to warrant cutting.

Rosterite. -Of special interest is the occurrence of this rare caesium-bearing variety of beryl in a quartz-microcline pegmatite 100 yards east of the abandoned bismuth workings on Harrisons Reward M.L. 26. On reputable authority it is stated that about 10 cwt. (500 kilos) are visible along the outcrop. An analysis yielded the following figures:—

ROSTERITE, MELVILLE.

SiO_2	Al_2O_3	Fe_2O_3	BeO	MnO	Li_2O	Na_2O	K_2O
64·64	19·10	·14	11·32	trace	·17	·31	trace

Rb_2O	Cs_2O	H_2O +	Total.	G.	No	Ne
1·42	1·72	1·21	100·03	2·74	1·584	1·5785

Analyst: D. G. Murray.

No traces were detected of Cr_2O_3, FeO, MgO, CaO, or CO_2. The analysis revealed quite considerable amounts of both rubidium and caesium. Like all other rosterites, it has a higher specific gravity and refractive index than common beryl. Hand specimens are devoid of crystal boundaries, and show only the slightest traces of the basal parting. Small patches of the specimens are perfectly colourless and transparent, but the greater part is slightly milky white, with a translucency of about 10 mm., the milkiness being due to minute fluid inclusions.

Rosterite has been previously described from Wodgina.*

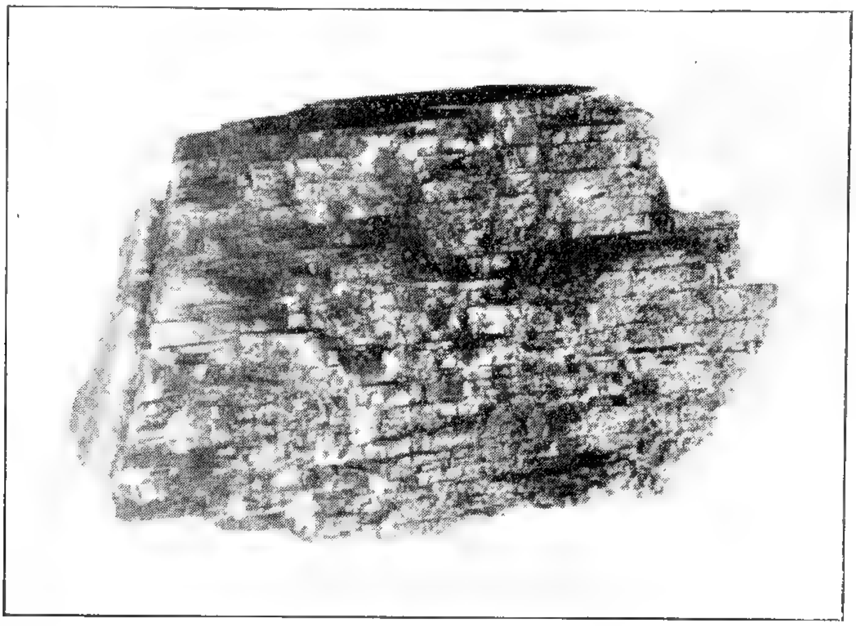
* E. S. Simpson, J.R.S.W.A. 15 (1929), p. 100.

(5).—GIGANTOLITE AND SPESSARTITE, MELVILLE, MUR.

Cordierite ($Mg_2Al_4Si_5O_{18}$) is a mineral of very characteristic structure in large masses, and highly susceptible to hydrothermal alteration into muscovite, with or without biotite and chlorite. Pseudomorphs of more or less impure muscovite after cordierite retain the characteristic structure of the original mineral, and are known as "gigantolite."

As far back as 1923 the Writer collected some typical specimens of gigantolite in the outcrop of a quartz-microcline-albite-muscovite pegmatite at the N.W. corner of Harrisons Reward M.L. 26. In 1932 the locality was re-examined, as in the meantime ilmenorutile had been discovered in the same vein. Further gigantolite specimens were obtained, and for the first time a detailed investigation of them was made in the laboratory.

Masses of several pounds in weight were not uncommon in the pegmatite outcrop, all showing the typical cordierite structure, especially the strong basal parting, irregularly spaced at intervals of 1 to 5 mm. See Fig. 2. The prismatic cleavages are less distinctly represented. Most of



GIGANTOLITE PSEUDOMORPH AFTER CORDIERITE, MELVILLE.

Scale of Nature. *Photo., B. L. Southern.*

Fig. 2.

the specimens have a number of small garnets dispersed sporadically through them, whilst coarse flakes of muscovite and biotite show up on the basal parting, and to a less extent on the vertical cleavages.

The gigantolite is greenish grey in colour, and is either pale or dark in shade according to the relative proportions of the various mineral constituents. Sections in three directions of one of the darker grey specimens showed no unaltered remnants of the original cordierite. The main mass consisted of micro-scaly muscovite, in which were embedded some larger flakes of muscovite and bottle green biotite. The latter was particularly plentiful along the lines of parting, but was also scattered in small groups throughout the whole mass. A little coarsely crystallised ilmenite, partly

altered to leucoxene, is present. Included garnets (spessartite) are not uncommon, and when lying across a parting do not seem to have displaced it, but on the contrary show a continuation of it right through the crystal in the form of a band free, or almost free, from microscopic inclusions. This shows that the garnet formed subsequently to the crystallisation of the cordierite. The only other inclusions noted in the gigantolite are occasional flakes of green chlorite, and a plagioclase in small lenticular masses with albite twinning and low extinction angle, indicating oligoclase.

One of the least weathered fragments was chosen for chemical investigation. It was rather pale grey in colour, with many embedded garnets somewhat larger in size than usual, and easily separated from the matrix. The whole was carefully crushed in successive stages, all the garnets being separated from the matrix, and both subsequently analysed separately.

The results of the two analyses were:—

GIGANTOLITE, MELVILLE.

	Micaceous Gigantolite.	Embedded Spessartite.
SiO_2	44·50	38·66
Al_2O_3	29·12	20·14
Fe_2O_3	5·72	·96
FeO	2·52	6·52
MnO	·41	32·06
MgO	3·06	·10
CaO	·24	1·62
Na_2O	·50	nil
K_2O	9·84	nil
H_2O	4·35	·16
H_2O	·17	·02
TiO_2	·04	nil
P_2O_5	·06	nil
CO_2	·08	nil
	100·71	100·24
G	3·0 +	3·985
Analysts:	J. N. A. Grace	C. R. Le Mesurier.

Calculation of the mineral composition of the main micaceous mass of the gigantolite, in the light of the analysis and microscopic examination, yields the following proportions of individual components:—

Muscovite	86 per cent.
Biotite	9 ,,
Ilmenite, Oligoclase, Limonite, Chlorite ...	5 ,,
	100 ,,

The embedded spessartite contains apparently a small proportion (5 per cent.) of siliceous impurities, seen under the microscope as a greyish dust. Allowing for this, the pure garnet molecules cocrystallised are:

Spessartite	78·7 per cent.
Almandine	16·0 ,,
Andradite	3·3 ,,
Grossularite	1·7 ,,
Pyrope	·3 ,,
	100·0 ,,

This spessartite is in globular individuals with only rare traces of a rhombic dodecahedron face. The diameters range from 1 to 4 mm. The colour is pale brown on the surface, and paler brownish white on a fresh fracture. They were not observed in any part of the pegmatite except in the gigantolite masses. They are very like the spessartites associated with tin ore at Moolyella. This is the third species of garnet to be recognised within a radius of a few miles at Melville, the other two being andradite* and grossularite.†

(6) PALYGORSKITE, DARTMOOR, MUR.

Palygorskite is a clay mineral closely related to Pilolite, and in describing specimens of the latter mineral from Wadara Hills in Series II. of these "Contributions"‡ the writer endeavoured to explain the relationship between them in the light of the modern theory of isomorphism. Assuming the two end members of the series to be the known mineral Halloysite ($H_4Al_2Si_2O_9 2H_2O$) and a hypothetical isomorphous mineral Picrocollite ($H_4MgSi_3O_9 2H_2O$) the following constitutions were suggested:—

Alpha-Palygorskite	Hal + Pic.
Beta-Palygorskite	Hal + 2 Pic
Wadara Pilolite	Hal + 3 Pic.
Alpha-Pilolite	Hal + 4 Pic.

A mineral recently collected at Dartmoor agrees very closely with the ratio for Beta-Palygorskite. It was found in two places, viz. on Hose's Loc. 7220, North Dartmoor, and on the Government Water Reserve 12648, South Dartmoor, 20 miles S.W. of Hose's.

The mineral at Hose's was got in considerable amount in the last 4 feet of a well 20 feet deep sunk in horizontally bedded sediments and yielding brackish water. The age of the rocks is not certain, but may be anything from Carboniferous to Cretaceous. The Writer did not see it in situ, but it was said by the proprietor to occur in "a thick seam at ground water level." Masses of it were lying on the dump up to 6 inches (15 cm.) in diameter.

Hose's palygorskite has the appearance of a tough creamy white to greyish white clay, but its unusual lightness and toughness were at once apparent. Subsequent tests in the laboratory showed that comparatively large fragments would float on distilled water until they became waterlogged. To the eye a fresh fracture appears dull, dense and structureless. That it is a mass of microscopic pores is, however, shown not only by the very low bulk specific gravity but by the strong adherence of one's tongue to it, and by the large amount of water it is capable of imbibing. When immersed in water it shows no inclination to swell, flake or crack. Its hardness is 1.5.

A single large lump of similar material was found alongside the Government water bore on Reserve 12648. The chief difference between this mineral and that on Hose's property was its greater hardness (2.0), toughness, and bulk specific gravity. Fragments sank immediately in water, but the porosity was still very high as judged by the strong adherence to the tongue, and increase in weight when soaked in water.

The powder of both minerals was identical in appearance under the microscope, consisting of slightly greyish translucent aggregates of extremely small birefringent flakes. The true specific gravity and mean refractive index were practically the same for both specimens.

* E.S.S.: J.R.S.W.A. 14 (1928), p. 52. † Not yet described in print.
‡ J.R.S.W.A. 13, p. 42–43.

Analyses showed very little difference between the two after they had been coarsely crushed and well, but not exhaustively, washed with distilled water to remove the salts of the brackish waters with which they were associated. The results were:—

PALYGORSKITE, DARTMOOR.

	Loc. 7220.	Res. 12648.
SiO_2	55·76*	56·49†
Al_2O_3	10·69	10·07
Fe_2O_3	4·58	5·00
FeO	nil	nil
MnO	·01	trace
MgO	6·85	6·63
CaO	·09	nil
H_2O —	9·04	9·51
H_2O	11·54	10·64
K_2O	1·10	1·39
Na_2O	·12	·32
TiO_2	·56	·46
Cl	trace	trace
Total	100·34	100·51
G (true)	2·20	2·21
Nm	1·522	1·523
Analyst:	H. P. Rowledge.	C. R. Le Mesurier.

* Includes 8·32 per cent. of quartz, rutile, etc., unattacked by fuming H_2SO_4, of which 0·96 per cent. does not vaporise with HF.
† Includes 10·66 per cent. of quartz, etc., of which 0·65 does not vaporise with HF.

Both minerals are decomposed by heating in powder with strong HCl or H_2SO_4. Quartz is readily detected under the microscope in the original powders, or by examination of the residues after acid treatment, followed by Lunge's solution. Under the latter conditions the titanium in the specimens is seen to be present as rutile. The potash may be simply adsorbed, or more probably present as muscovite. If the latter, it forms about 10 per cent. of the whole in the first, and 15 per cent. in the second.

Making allowance for these impurities, the ratios of MgO, Al_2O_3, SiO_2 and H_2O to one another prove to be—

Source.	MgO	Al_2O_3*	SiO_2	H_2O +
Loc. 7220 ...	1·92	1·00	8·09	12·44
Res. 12648	2·21	1·00	8·96	14·57

The former mineral corresponds very closely to—

$$H_4Al_2Si_2O_9 \cdot 2H_2O + 2\ (H_4MgSi_3O_9 \cdot 2H_2O).$$

which is the formula for Beta-Palygorskite.

More uncertainty is introduced into the calculation of the second mineral owing to the appreciable amount of soda present, only part of which is likely to exist with the potash in muscovite. The figures given are those based on an assumption that two-thirds of it are present as muscovite. The ratios so calculated are not far from—

$$H_4Al_2Si_2O_9 \cdot 2H_2O + 2\tfrac{1}{4}\ (H_4MgSi_3O_9 \cdot 2H_2O)$$

In general, therefore, the analytical figures obtained appear to support the Writer's theory of the constitution of the Pilolite-Palygorskite series.†

* Includes Fe_2O_3.
† Jour Roy Soc. W.A. 13, p. 43. Key to Mineral Groups, Species and Varieties, E. S. Simpson, 1932, p. 56, 58.

(7) PETALITE, LONDONDERRY, CEN.

Whilst inspecting Seahill's felspar quarry on M.L. 72 at Londonderry this spring, the writer observed a hard, almost opaque white mineral, obviously not microcline, of which quite a ton had been thrown out on to the waste heap. This was traced to the south-western corner of the quarry, an excavation 50 x 50 x 12 feet, from which about 2,000 tons of high-grade microcline have been taken. The white mineral formed in situ (so far as could be seen) a large vertical tabular mass, associated with a parallel mass consisting of an intergrowth of coarsely crystallised lepidolite and albite, both close to, if not on, the wall of the microcline vein.

Close examination of the specimens collected indicated that the white mineral was a deep seated alteration product, pseudomorphous after a transparent colourless mineral, of which a few small unaltered cores remained. The well marked cleavage of this latter mineral, its low specific gravity (2.39) and refractive indices (1.516, 1.510, 1.503)* pointed to its identity with Petalite, $LiAlSi_4O_{10}$, a mineral not previously found in Australia. This determination was confirmed by a chemical analysis.

PETALITE, LONDONDERRY.

	Petalite.	Pseudomorph after Petalite.
SiO_2	76·19	74·48
Al_2O_3	16·48	15·52
Fe_2O_3	·21	·17
FeO	nil	nil
MnO	trace	nil
MgO	·54	·11
CaO	nil	·20
Li_2O	3·72	nil
Na_2O	·36	7·72
K_2O	·18	1·22
H_2O—	1·04	·40
H_2O –	1·22	·50
Total ...	99·94	100·32
G	2·38	2·61

Analyst: C. R. Le Mesurier.

Some of the least altered mineral that could be obtained was used for the analysis. It was highly transparent, colourless to very faint pink or lilac in colour, possessing a bright vitreous lustre, and one well marked cleavage (001). One cleavage fragment shows a rough face making an angle of 62 degrees with it, which may be *z* $(\overline{9}05)$, since *cz* is recorded as 62 degrees 33 minutes. The mineral is very brittle, and has a hardness of 6.

Even the purest mineral is not completely unaltered. Examination with a lens reveals ribbons and threads of less transparent white material forming an open meshwork in it. This is a hydration product, as the analysis shows an appreciable percentage of unessential water, whilst a little alkali appears to have been leached out, the calculated ratios being—

	SiO_2	Al_2O_3	$(Li, Na)_2O$	H_2O +
Petalite, theory ...	8	1	1	nil
Petalite, Londonderry	8·10	1·05	0·85	0·35

These figures do not include the appreciable MgO whose role is unknown, but which may be present as montmorillonite.†

* Determined by H. Bowley. Minl. Mag. 20, p. 141.

† Cf. W. F. P. McLintock, Petalite at Okehampton, Devon.

Petalite appears to be very susceptible to alteration under the influence of the hydrothermal activity which marks the final stages of pegmatite formation. At Londonderry at least three different pseudomorphs have been observed, viz.:—

(1) A hard lilac-coloured mineral, partly dense, partly cellular.
(2) A softer and more brittle mineral of the same colour (montmorillonite?).
(3) A hard dense and tough, milk white mineral.

The last is by far the most abundant, and is to be seen in masses many pounds in weight on the dump. It was this mineral which was found to enclose cores of petalite with indefinite boundaries between the two, and with the perfect cleavage of the original mineral continuing into the pseudomorph as a more or less pronounced parting. It is also the only one which has been examined in detail, the analysis of a typical piece being given above. As this pseudomorph occurs in the quarry in masses several hundredweight in weight, it is certain that petalite originally existed in similarly sized masses, and may be disclosed in large unaltered masses as quarrying proceeds.

Apparently homogeneous, the microscopic examination of powder and section of the pseudomorph shows it to consist of small interlocking grains of a colourless, transparent, birefringent mineral with a refractive index a little below 1.538, crowded with minute granules of a second mineral. The analysis permits this to be interpreted as a mass of microcystalline albite (66 per cent.) with granular inclusions of quartz (25 per cent.), and probably some minute scaly muscovite and a "clay" (montmorillonite?) (9 per cent.). Occasional minute scales of the former and films of the latter are visible on the partings.

A second specimen had a specific gravity of 2.64, and contained 72.55 per cent. of silica.

If petalite were altered into albite according to the equation-

$$2LiAlSi_4O_{10} + Na_2CO_3 \Rightarrow 2NaAlSi_3O_8 + 2SiO_2 + Li_2CO_3$$

and 10 per cent. of the albite further altered into montmorillonite, thus -

$$2NaAlSi_3O_8 + MgCO_3 + 6H_2O \Rightarrow MgAl_2Si_5O_{14}\cdot 6H_2O + SiO_2 + Na_2CO_3$$

and all the silica and montmorillonite left in situ, the resulting pseudomorph would contain albite 72 per cent., quartz 20 per cent., montmorillonite 8 per cent. This is not far from the observed proportions.

In mass the pseudomorph is easily distinguished from the primary microcline and albite of the vein. It has a peculiar, somewhat horny, lustre, is milk white, has a translucency of about 3mm. and a hardness well over 6. The basal cleavage of the original petalite is perpetuated as a much less perfect parting, which varies in intensity in different specimens, and even in different parts of the same specimen. In places it is closely spaced, 1 to 3 mm., in other places it is only observed at intervals of a centimetre or more, whilst individual planes do not always pass completely through the pseudomorph.

This pseudomorph is quite different to those which have previously been described in the literature, viz., hydrocastorite in Elba, and montmorillonite in Devonshire.

Except for two doubtful records, petalite has previously been found in only six localities throughout the world, viz.: (1) Utö, Sweden (type locality); (2) San Piero, Elba; (3) Okehampton, Devonshire; (4) Amanaus Glacier, Caucasus, Russia; (5) Bolton, Massachusetts; (6) Peru, Maine. The doubtful localities are: (7) Roschitz, Moravia, Czecho-Slovakia; (8) York (near Toronto), Ontario.

(8) TOPAZ, MELVILLE, MUR.

Early in 1932 a prospector (O. Drew) discovered what he took to be barite in a pegmatite vein just south of the place known as 'The Basin," at Melville. Examination in the laboratory showed that the mineral was topaz. Later in the same year the writer visited this find, and discovered more topaz in another vein about 200 yards south of the first find, and muscovite pseudomorphs after topaz in both places. Still later Drew found topaz again on Harrison's Reward M.L. 26, about 1½ miles north-west of the first find.

In the first vein, which is on the outer slope of the southern rim of The Basin, the mineral occurs in a quartz-microcline-albite pegmatite. It is in colourless, or slightly milk white, masses up to several pounds in weight. That each of these is a single crystal individual is shown by the continuity of the distinct basal cleavage. The only crystal outlines observed were some isolated groups of striated prism faces. Parts of the masses are completely colourless and transparent in a thickness of 5 mm., and for the most part the translucency reaches to 10 mm.

An analysis was made of some of the cleanest, almost colourless mineral. The figures obtained were:—

TOPAZ, MELVILLE.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	F	H_2O +	H_2O —
32·80	54·66	·28	nil	nil	18.55	·87	·05

Total.	Less O = F	Net Total.	G
107·21	7·81	99·40	3·54

Analyst: D. G. Murray.

This yields a molecular ratio of: –

	Al	:	F + OH	:	Si
Melville Topaz	2·00		2·00		1·04
Theory	2		2		1

In addition to the minerals already mentioned the vein carries some green beryl and a little manganotantalite.

In a second vein just south of the above, colourless topaz occurred under similar conditions, this time with a pale yellow beryl. The only specimen received from the third locality was similar to that from the first, being slightly milky white with considerable translucency.

One of the most interesting points about all three occurrences of topaz is the extent to which the mineral has been altered into pseudomorphous muscovite in a later stage of the history of the veins, when apparently they were invaded by hot alkaline solutions rich in potash.

In the first vein, apart from large masses of pure unaltered topaz, there are many masses consisting of a core of topaz completely surrounded by a thick layer of soft, but tough, cryptocrystalline muscovite. In a typical

specimen the unaltered core has a rounded rhomboid cross section, measuring 6 x 4 cm. at the middle, and tapering off at each end to about 2 x 1½ cm. This core breaks out cleanly and sharply from the enclosing muscovite shell in which it is not quite centrally situated. The encrusting layer of mica varies in thickness from 0.3 to 2.0 cm.

In a specimen from the second vein a similar micacisation is much further advanced, the pseudomorphous muscovite reaching 3 cm. in thickness. Here, instead of forming a sharp boundary with the parent mineral, it penetrates the latter in tongues and loops.

At the third locality also advanced stages of micacisation have been observed in addition to almost completely unaltered mineral. This further evidence of a late potassic phase in the formation of pegmatites in this district supports that already observed above in the conversion of primary cordierite into muscovite and biotite in a pegmatite on Harrison's Reward Lease, and in the widespread conversion of amphibole into biotite on the walls of the pegmatite veins.

SUMMARY.

A description is given of the occurrence in Western Australia of the following minerals, with analyses and details of physical properties, genesis, etc.

(1) Antimony ochre, Wiluna. A dense mixture of stibiconite, cervantite, atopite (?) and quartz. (2) Apatite, barite and glauconite, in Cretaceous beds, Gantheaume Bay. The apatite occurs as coprolite pebbles and apatised coniferous wood. (3) Native arsenic, in a gold lode, Kalgoorlie. (4) Beryl (common beryl, emerald and rosterite), Melville. The emerald found is promising, but not yet commercial. (5) Gigantolite and spessartite, Melville. The latter is embedded in the former, which is a pseudomorph after cordierite. (6) Palygorskite, Dartmoor. The first record for Australia. Analyses confirm the Writer's theory that this mineral is a cocrystallisation of halloysite and picrocollite. (7) Petalite, Londonderry. The first record for Australia. The original mineral and a common pseudomorph are described. (8) Topaz, Melville. Details are given of the primary mineral and a muscovite pseudomorph.

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

4 CUBARIS SPENCERI, A NEW TERRESTRIAL ISOPOD, FROM THE NORTHERN TERRITORY OF AUSTRALIA

by

HELENA M. BARNES, B.Sc.

Read: 10th October, 1933. *Published*: 22nd June, 1934.

INTRODUCTION.

The Isopod, which forms the subject of this paper, was collected by Professor W. Baldwin-Spencer in 1911, from the Little Red Lily Swamp, Roper R., Northern Territory, Australia, and belongs to the family Armadillidiidae. In recognition of the collector I have named this new species *Cubaris spenceri.* It differs from *Cubaris*, Brandt, in having the frontal marginal line cleft. In this respect it agrees with Chilton's species *C. helmsianus* from Barrington Tops and the species referred by Stebbing to *C. cinctutus* (Kinahan), described in Willey's Zoological Results, Pt. V.: also with *C. ambitiosus* of Budde-Lund. In each of these species the amount of indentation is different, the species under discussion having the most pronounced cleft. The depression in the case of *Cubaris spenceri* is deeper and wider, and more triangular in shape than in *C. helmsianus*. In the case of *C. cinctutus* the cleft is narrow and deep. In addition *C. spenceri* differs from *Cubaris*, Brandt, in the absence of coxopodites on the epimera. At some later date these species may have to be removed from Cubaris and transferred to a new genus. *C. spenceri* differs from Chilton's species in having three spines on the terminal segment instead of two ridges. By comparison of the two papers other differences, not mentioned here, will be found. These I consider to be of less importance. Reference to Chilton's paper will supply the necessary facts. From the literature available no references have been found to any Cubarid in which a cleft telson has been observed. For this reason it has been classified as a new species.

Cubaris spenceri, sp. nov.

Pl. III.

The following description is taken from a male specimen.

Body (Pl. III—fig. 1):—oblong oval in shape, slightly convex and capable of being rolled into a ball. When outstretched it has, in the larger specimens, a flattened appearance due to the extensive development of the epimera; surface scale-clad and tuberculate, with, in addition, scattered setae and "schuppenborsten" (Wahrberg). The tubercules are regularly arranged and more prominent on the posterior than on the anterior segments.

Cephalon (Pl. III—fig. 2):—flanked by the epimera of the first mesosomatic segment, upper surface tuberculate; the sides are lobate, the posterior margin practically straight, but with a median transverse ridge just above it giving a raised appearance in the mid-line, anterior margin well-defined, lateral lobes present, and on either side of the mid-line, with their bases almost confluent with the anterior marginal line, are two prominent raised ridges; anterior and posterior margins distinct, the former extending to meet

the vertical marginal line, which runs obliquely through the pleural parts of the head to meet its dorsal border. The vertical marginal line also meets the frontal marginal line. The Clypeus is short, convex, tuberculate, and more than twice as long as broad. Epistome slopes inwards, and at the frontal marginal line is out-turned, its surface uneven, being convex laterally and in the mid-line. The posterior portion of the mid-line is hollowed due to a swelling on either side, corresponding in position to the ridges on the cephalon. The frontal marginal line is very prominent laterally, being raised on either side into a crest but the central part is less marked. The supra-antennary line is high. The antennal rings are well-marked and slightly oblique in position.

Eyes:—moderately large, compound, and lateral in position situated halfway between the anterior and posterior margins.

Segments of Mesosome:—sub-equal in length, with the exception of the first which is longer than the others and has its anterior margin convex and thickened, posterior margins of segments one to five are practically straight, those of the sixth and seventh distinctly concave. The dorsal surface of each segment has ornamentation in the form of tubercles and ridges. On each of the segments is a median longitudinal ridge, which is only faintly marked on the first three segments, but which shows very definitely on the last four. In addition to these are, on either side, a number of tubercles which, as in the case of the ridges, are more marked on the posterior than on the anterior segments. These tubercles are definite in number and their arrangement can be seen from the figure (Pl. III—fig. 1). The first segment has, in addition to these, slight swellings towards the anterior margin, on either side of the mid-line.

Epimera:—large, flattened and recurved, margins fringed with short fine setae. The posterior angles of the first pair are acute, similarly those of the second, third and fourth, the angles of the fifth, sixth and seventh tending to approach right angles. No definite coxopodites are present on the undersides of any of the epimera.

Metasome:—continuous in outline with the mesosome. The first five segments are sub-equal in length. The lateral portions of the first two are covered by the epimera of the last mesosomatic segment, those of segments three to five being large, flattened and recurved. A single median ridge is present on each of the first two segments, but the third, fourth and fifth have in addition to this two lateral tubercles, one on either side of the mid-line.

Terminal segment (Pl. III—fig. 8):—tetragonal in shape, constricted in the middle, and broader at the base than at the apex, armed anteriorly with two tubercles, one on each side of the median line. Posteriorly is a single median elongated ridge; anterior portion convex, posterior flattened and upturned. The posterior margin is truncate, fringed with setae, and has a deep median cleft.

Uropods (Pl. III—figs. 9 and 10):—roughly tetragonal in shape with the inner margin inflected, anteriorly is a thickened portion. Attached as far forward as possible, on the inner mesial border is the endopodite, which is more than half the length of the basal joint, setose and with a long apical spine. The exopodite is small, not visible from the ventral surface, and attached to the basal joint towards its inner border, halfway between the anterior and posterior margins. At the point of attachment is a prominent

ridge. It is also setose, with a single apical spine. Setae are present on the margins of the basal joint. The uropoda are continuous in outline with the terminal segment, and do not project beyond.

Antennules:—small, scarcely reaching to the posterior margins of the antennal orbits; proximal joint (Pl. III—fig. 3) is large, the second very short and narrower than the first, the third more slender and longer than the second, but shorter than the first; joints not situated in the middle of one another but towards the outer side, making the outer margin almost straight and the inner irregular; first and second joints devoid of setae, but sensory setae present on the distal joint, sub-apical in position and situated towards the inner side, stout in appearance, numerous and arranged in a compact group. The outer side of the distal joint is produced in a spine.

Antennae (Pl. III—fig. 4):—short, slender and setose, in their folded position reaching about two-thirds of the way down the epimera of the first mesosomatic segment; first joint is short, less than one half the length of second, third shorter than the second, second and fourth sub-equal; the fifth longer and more slender than the fourth. The flagellum is slightly shorter than the terminal joint of the peduncle, and has its first joint only about one-fourth shorter than the second. The sensory process is well-formed and has a long basal portion, marked off from the apical portion by two short spinous setae. In addition to these a number of other setae are present on the basal portion -apparently, three short and three long one above the other on each side. Surrounding the apical portion are a number of spinous setae of equal height.

First maxilla:—outer lobe broader than the inner, and armed apically with nine setae, inner five single pointed, and less chitinous than the outer four, which are also simple; outer distal margin fringed with setae; inner lobe has the outer apical point produced in a tooth and bears terminally two stout bushy setae.

Second maxilla (Pl. III -fig. 5):— outer and inner lobes practically equal in height, angularly produced near its base, inner lobe more chitinous than the outer. Both have a covering of setae, which tends to be fine and long on the outer lobe, short and spinous on the inner. A number of long setae are present towards the inner margin of the outer lobe, at the point where the two lobes touch.

Maxilliped:—basal joint roughly rectangular, the second with the outer margin curved, endite truncate apically with inner apical point acute, outer rounded. Three moderately long, strong spines are situated towards its apex. The endopodite longer than the endite, bears on its inner margin two groups of setae, each of which has one long spine. On the outer margin are two single setae, and at the apex is a tuft of numerous short setae. The first joint of the endopodite has two long spines situated close to each other. The epipodite reaches more than halfway up the basal joint and has its apex sub-acute. The terminal portion is figured. (Pl. III– fig. 6.)

Upper lip:—rounded, short and without setae. *Left mandible* (Pl. III —fig. 7:—both cutting edges strongly chitinous, the outer consisting of three large teeth, one of which is bilobed; the inner, of four teeth; ciliated lappet very evident, rounded and extremely setose. Three penicilla are present (P. 1 + 2), two occurring on the ciliated lappet, one below; and also the usual large bushy seta. *Right mandible*:—outer cutting edge composed of

two large bi-lobed, chitinous teeth, the less chitinous inner cutting edge indefinite in form, appearing to consist of a single tooth showing bi-lobation; ciliated lappet setose, less prominent than in the left mandible, and irregular in form, bears a single penicillum, another being present below it (P. 1 + 1). The seta representing the molar tubercle is the same as that occurring on the left.

Lower lip:—two lateral lobes setose distally, with their apical margins armed with a number of short spines inwardly directed; median portion is setose and appears to be divided into lobes, each of which is rounded apically.

Walking legs:—rather feebly developed and increase in length posteriorly from the first to the seventh; second to the seventh the same in form and proportion, the first differing from them in having the carpus and propodus swollen, more particularly the carpus, and proportionately shorter than the remaining joints. In all the ornamentation of the spines and setae is along similar lines, the carpus and merus of the first four pairs being, however, more profusely armed than in the remainder. The basis : ischium : merus : carpus : propodus : dactylos as 3.2:1.6:1:1.6:.5 in all except the first which has the proportions as 3.2:1.6:1:1.4:1.2:.3.

The joints of the first pair of legs are proportionately wider than those of the remaining legs. The basis is rectangular in shape and has both the inner and outer margins covered with fine setae, one or two longer spines being present at the apex of the inner margin.

As in the case of the basis, the ischium, which in form is roughly rectangular, with the upper end slightly swollen, has its margins finely setose, two spines being present at the distal end, one on either side.

The merus is further differentiated tending to be triangular in shape, with the apex rounded at the lower end. Its outer margin is finely setose with two large spines at the upper end. The inner margin is profusely armed, except in the case of the last three pairs of legs, as mentioned above, which have the spines fewer in number and also the majority of smaller size. The carpus is swollen in the first pair of legs, rectangular in the remainder. In all the outer margin is finely setose, the inner of the first four pairs profusely armed with setae of unequal length, but of the same form, of the last three, less profusely armed. The rectangular propodus, slightly widened at the lower end has its outer margin finely setose, the inner armed with spines. As mentioned above in the first pair of legs it is swollen. The dactylos is simple, setose at the base, and has a long simple spine at the inner apical margin.

Pleopods:—overlap one another from before backwards, and in the five pairs tracheae are present in the exopodites. The exopodites of the first pair are almost rectangular with no setae, and lie parallel with the basal joint. In the second pair they have their apices drawn out, in each case, into a long process with a rounded apex, and their outer margins setose, the setae extending part way up the inner margin. The third pair has the exopodites rectangular, with one corner drawn out into a rounded point, is marginally setose and has a number of spines present on the surface. The fourth and fifth pairs are rectangular, with the corner less drawn out than in the case of the third, with setose margins and spines present on their respective surfaces. The endopodites of the first are broad at the base and narrow apically, the apical point provided on the inner side with a number of spines. In the second pair they are two-jointed, with the second joint long drawn out into

a slender pointed process, which extends some distance beyond the end of the exopodite. The endopodites of the third, fourth and fifth pairs are triangular, with rounded apices, gradually decreasing in size from the third to the fifth.

In the *female* all the legs are of the same form and proportion, the first pair not having, as in the male, the carpus and dactylos swollen. It differs further, in having fewer setae on the merus and carpus of the first four pairs of legs, the number of setae being approximately equal in the seven pairs. The general arrangement of the setae is the same as in the male.

As in the male all the pleopods have tracheae. The first and second have the exopodites more or less rectangular in shape, with setose margins, the third and fourth are rectangular with the corners less drawn out than in the male. Their margins are setose and spines are present on the surface. The fifth is smaller and nearer to the male form. The endopodites of one and two are reduced, that of the second being in the form of a small elongated chitinous plate, of the first scarcely apparent. In the case of the third, fourth and fifth the structure is the same as in the male.

A number of females with eggs present in the brood pouch are in the collection. They are smaller and less rugose in condition than the males, but the general form of the body is the same, also the arrangement of the ridges and tubercles. As mentioned above, a difference occurs in the ornamentation and form of the legs. No dissimilarity is noticed in the mouth parts.

Size:—length 11mm., breadth 6mm., being the measurements of the largest specimen—a male.

Colour:—in spirit, pale with brownish markings; older specimens darker; epimera lighter than remainder of dorsal surface.

Habitat:—Little Red Lily Swamp, Roper R., Northern Territory, Australia.

REMARKS.

The whole of the body including the appendages is covered with scales, which vary in form. The portion of each segment underlying the preceding one, has the scales more flattened, fewer in number and less tile-like in arrangement than the uncovered portion. Simple setae are scattered over the surface of the segments and on the lateral margins of the epimera. Also, occurring on the dorsal surface of the uncovered portion are "schuppenborsten" (Wahrberg) as shown in text-figure 1, 2c and 2d. Setae differing from the simple form, are found on the thoracic appendages. Those on the form text-figure 1: 1a, occur on all the mesosomatic appendages of both the female and male. The form text-figure 1: 1b, is found on all the appendages of the female and apparently only on the fifth of the male. Confined solely to the merus and carpus of the first three pairs of male appendages and also occurring on the carpus of the fourth pair is the form text-figure 1: 1c. This latter form may possibly be a secondary sexual character, as it appears to be altogether absent in the female and immature forms.

With age the ridges of the segments become more prominent, and the epimera larger and more flattened.

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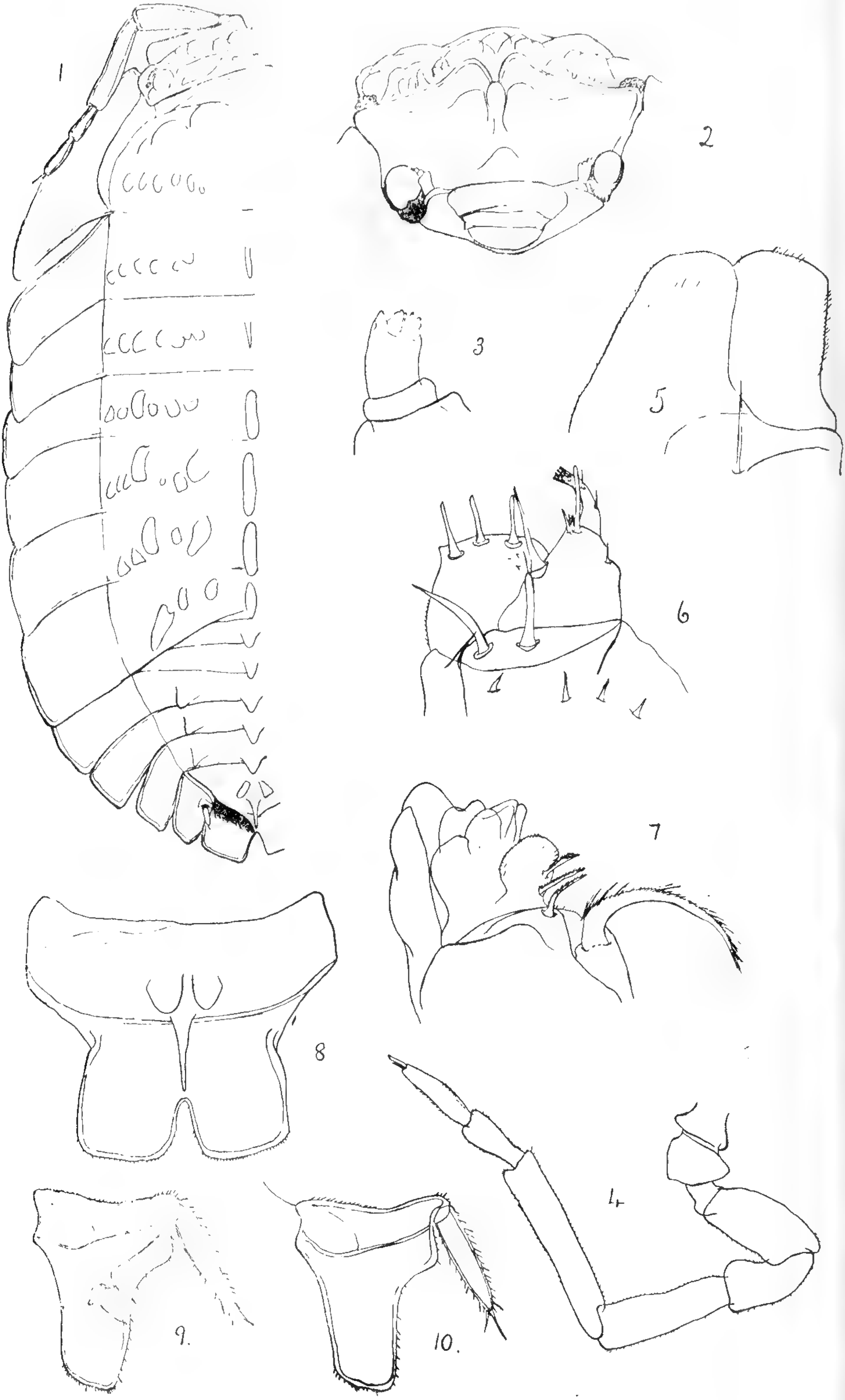
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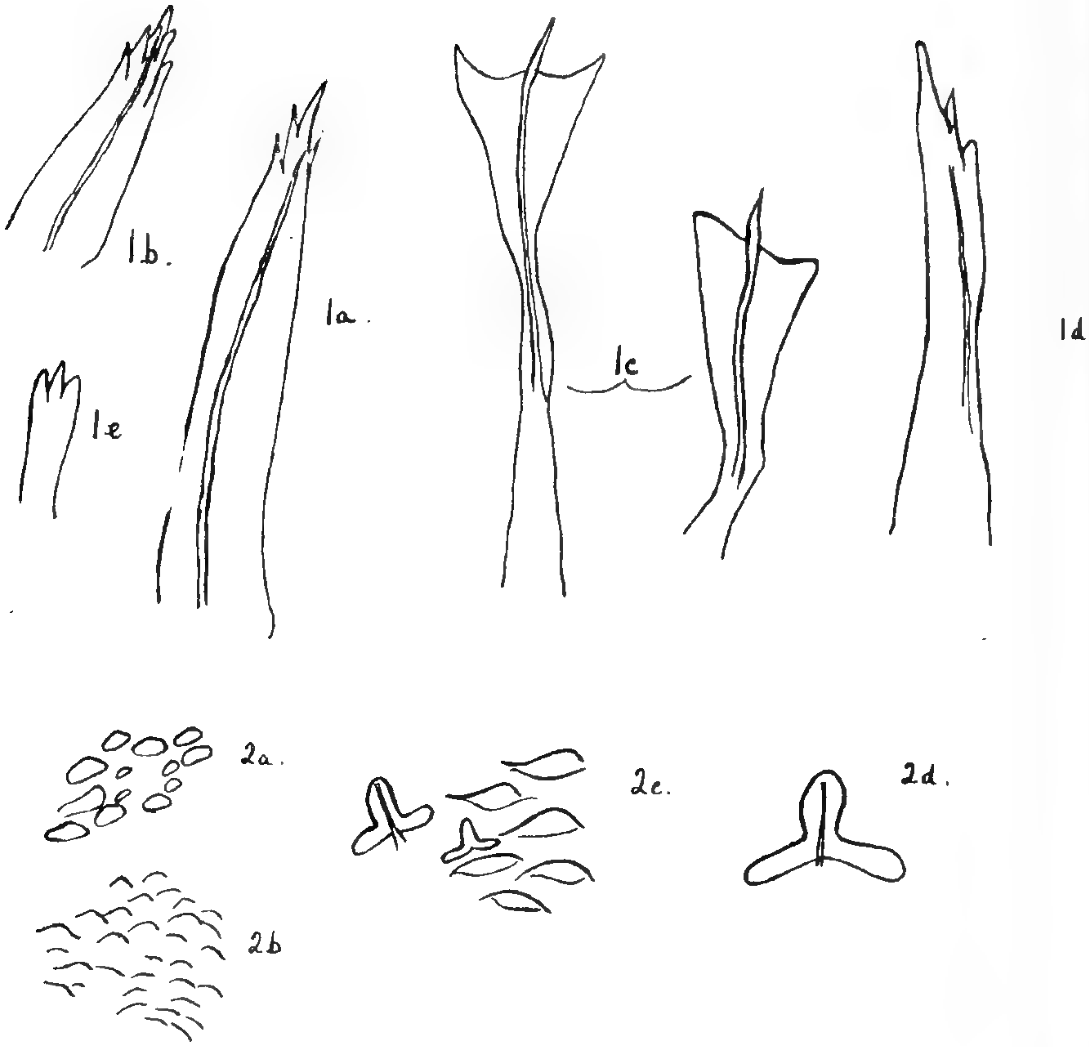
Explanation of Plate III.

All the figures refer to **Cubaris spenceri** and are drawn from a male specimen.

Fig. 1. Dorsal view of entire animal.
2. Anterior view of the cephalon.
3. Terminal portion of antennule.
4. Antenna.
5. Terminal portion of second maxilla.
6. Terminal portion of maxillipede.
7. Terminal portion of left mandible.
8. Terminal segment.
9. Dorsal view of uropod.
10. Ventral view of uropod.



Explanation of text-figure 1.

Types of setae and scales found on the body and appendages of Cubaris spenceri.

1.—*Mesosomatic appendages*: a, All of male and female; b, All of female and 5th of male; c, 1st-3rd of male, confined to merus and carpus and 4th of male confined to carpus; d, 1st of male confined to propodus; e, 6th and 7th of male.

2.—*Body*: a, Scales occurring on covered portion of mesosomatic segments; b, Scales occurring on uncovered portion of mesosomatic segments; c, Enlarged scales as seen on uncovered portion; d, Form of "schuppenborsten."

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5.—MINERALOGY OF THE FINE SANDS OF SOME PODSOLS, TROPICAL, MALLEE, AND LATERITIC SOILS.

BY DOROTHY CARROLL, B.A., B.Sc. (Hons.).

Read 8th May, 1934. Published 15th June, 1934.

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INTRODUCTION.

The identification of mineral grains in the fine sands of soils is an interesting study in itself, but it has a practical application in that it gives some indication of the processes which result in the formation of a soil, and often of the parent rock of that soil.

The unit of soil study is the profile (a vertical section from the surface of the soil to the underlying parent material as seen in the field) the development of which largely depends on climatic conditions and topography, but "The properties of the rock pass on to the soil, either wholly or in part. The soil afterwards acquires new properties. Consequently we must distinguish between *inherited* properties and such as are *acquired.* These two sets of properties stamp the soil as a living object . . . . . ." (J. van Baren, 1928, p. 161.)

The inherited properties include mineral fragments, which are found principally in the sand fractions, while the acquired properties will be found in the silt and clay fractions, and are formed from the original minerals of the parent rock by weathering, or acquired from outside sources. Sometimes the acquired features of soils are of more importance than the inherited, as is exemplified by certain Mallee soils of Western Australia, which owe their characteristic features to the accumulation of cyclic salt (Prescott, 1931, p. 16). (Mallee soils are alkaline soils formed under low rainfall (10-15 inches). They vary from sands to clays and have an accumulation of calcium carbonate in the subsoil at a depth of 8 to 20 inches. (Teakle, 1929-30, p. 83.)

Climate was once thought to be the most important factor in the production of soil types (Glinka, 1928), for it causes, over large areas similar conditions of temperature and moisture, under which the complex changes in the rock debris take place. Climate will undoubtedly greatly influence the physical condition and the profile; for example, a podsolised granitic soil differs from a granitic soil in a Mallee area, but variation in the bedrock is the main factor in producing sands, clays, loams, etc., and indeed, podsols only attain perfect development where the soils are sandy. Clay material in podsol soil zones does not form a podsol. Differences in parent material are often manifested by variation in the natural vegetation, and are more definitely brought out by detailed soil mapping. Thus in the Kuitpo district of South Australia (Taylor and O'Donnell, 1932) the various soil types are clearly dependent on the underlying rock and the topography.

The inherited properties, if the soil has not been completely changed during formation, indicate the nature of the parent material, and determination of the fine sand minerals should be a quick method of finding out the parent rock, but this is complicated by the great variety of rock types which grade into each other (this applies to the igneous and metamorphic rocks), and by changes which have taken place either in the first stages of rock weathering, or in the soil itself, the less stable minerals quickly disintegrating and giving rise to secondary minerals which are often difficult to identify with certainty (*e.g.,* clay minerals). The older a soil the more its character differs from that of the parent rock and the greater the accumulation of stable accessories, and secondary minerals, provided the parent rock will continue to respond to weathering. A sandstone soil newly weathered would not differ much from an old sandstone soil.

Stable minerals, the stress minerals of Harker, are useful when considering type soils developed from rocks of different composition. The tabulated results in this paper show that these stable species are present in nearly all the soils examined, but they are present in varying amounts. A "flood" of

zircon would not be expected from a basic rock, nor one of magnetite or ilmenite from a granitic rock. Ferromagnesians may be accessories in soils from granitic rocks, will form an appreciable part of soils from basic rocks, but will be absent, or practically absent, from ancient soils, as for example, lateritic soils.

Not only is the amount of any species in a soil of importance, but also the forms developed. Zircon from different localities is often of distinctive appearance. The zircons in the King Island soils are readily distinguishable from those found in the Mallee soils of Western Australia.

The change of sedimentary rocks to soils involves, as a rule, mechanical and physical, rather than chemical processes, but residual limestone soils are an exception. Where the parent material of a soil is a sediment, *e.g.*, Myponga sand, it is impoverished in species.

The *acquired* properties of soils are difficult to interpret, and yet, when correctly interpreted, give the key to the processes of soil formation. These features will indicate, by the kind of secondary grains formed, the type of weathering to which the soil has been subjected. In identifying these acquired properties one must remember that the minerals of the fine sand are the remains of parent rock minerals, and that they have given rise to the materials of the silt and clay fractions by the action upon them of the soil solution containing acids and bases. The soil solution depends on the weatherable minerals in the soil and on the climate and topography for its chemical composition. The soil water from a low-lying area is not the same chemically as that from a hill-top or elevated tract of country. The soil solution will act on any unweathered minerals in the mineral residue thus promoting further soil formation. The process must be very slow, even geologically speaking. A mature soil is one which has lost practically all its unstable grains, whether these have been changed into the clay complex, or into more stable forms, such as leucoxene and anatase from ilmenite.

Kaolinisation is one of the most important weathering processes. "Kaolinisation in the strict sense of the word is to be attributed to some form of hydrothermal action, and it can therefore scarcely be looked upon as a normal form of weathering, but impure kaolinic clays, often called lithomarge, either white (pot-clay and pipe-clay) or stained various colours by the oxides of iron or manganese, do result from what appears to be normal weathering" (Rastall). G. W. Robinson ("Soils" 1932) states definitely "that kaolin, whose characteristic mineral is kaolinite, is the product of deep-seated hydrothermal decomposition, which differs entirely from the epigene processes whereby soils are formed." "The kaolinisation theory is inadequate as a general explanation of the clay complex, although the clay complex may contain kaolinite or minerals similar in constitution to kaolinite, formed by epigene processes." C. S. Ross (1927) stresses the fact that the essential clay mineral found in soils is beidellite, a member of the montmorillonite group with the formula, $Al_2O_3.\ 3SiO_2 - 4H_2O \pm$. Of kaolinite he states, "It is usually, if not always, the result of action of hot mineral-charged solutions that escape from cooling igneous masses, and can be almost completely eliminated as a possible soil or shale component." In a later paper with Kerr (U.S.G.S. Prof. Paper 165—E) it is stated that "The less profound weathering conditions seem very commonly to produce beidellite-like material, but where the weathering and leaching are very profound kaolinitic material may be produced."

In some soils true kaolinisation appears to have taken place. A soil developed from recent volcanic material from Java is a possible example, as it has been deeply weathered and contains vermicular crystals of kaolinite

at depth (156a, b, c, d); 156a may represent the weathered volcanic material itself. Maxwell, quoted by Prescott (1931, p. 70) in discussing the basaltic soils of Hawaii, suggested that the basalt had received a preliminary weathering (surely alteration, not weathering) while in the form of lava under the action of volcanic steam and sulphurous acid. The fact that the weathering is much more complete at the base than at the top of the profile studied, and that species occur at the top which are absent lower down, to a certain extent confirms Maxwell's views. It is thought that a similar process might account for the red loams formed from basalts in the Eastern States (Australia) (Prescott, 1931), and although mineralogical features indicative of this process were not recognised in the samples (906, etc., Carroll, 1931-32) examined microscopically, soil from several feet below the surface might resemble that from Java.

Small grains found in the light fractions of soils (described in a later part of this paper) have resulted from the alteration of the original minerals of the soil. The optical properties of these grains vary slightly from one locality to another, and there is evidently a relation between the type of clay mineral and the climatic and other physical conditions under which it is formed (Ross, 1927). This variation has been noticed in the samples examined, the clay minerals even varying in different parts of the same profile (see percentage composition of Lake Brown light fraction).

Leucoxenic alteration.—Leucoxene is generally considered to be a variety of sphene produced by the alteration of ilmenite, as is to be seen in many rocks. Because of its composition, lime is necessary for its formation, and this suggests that it may be possible for leucoxene to form in soils rich in lime. Leucoxene is an abundant constituent of some heavy fractions of fine sands, but not all soils containing lime and plenty of ilmenite have a large development of leucoxene. Under acid conditions anatase and brookite will form from titania in the soil solution, but it is not considered likely that leucoxene could form directly in this manner. All the leucoxene in a soil may not have formed in situ, the parent rock having contributed most of the grains. The soils from King Island, Tasmania, provide an interesting example of the variation of leucoxene content with topography. Three types of sandy soil from the island, all very similar mineralogically, and evidently derived from similar parent material, were examined. The *Pegarah* fine sandy loam (see later part of this paper) contains abundant ilmenite, and but little leucoxene; the *Naracoopa* sand, over deep, well-drained sand, while similar in other respects, has a fair development of leucoxene and rutile; the *Lappa* sand, over deep sand, poorly drained, differs from the two previous types in the abundance of leucoxene, which in the surface soil is twice as plentiful as ilmenite, and in the three lower horizons is practically equal in amount to ilmenite. This suggests that ilmenite has given rise to leucoxene under acid conditions, although a certain amount of carbonate was probably contained in the dune sands from which this soil was derived. Possibly acid conditions are necessary to liberate the lime. A chemical analysis is needed to show whether the soil now contains lime which, under a continuance of favourable conditions, would combine with titania to form leucoxene. The leucoxene only indicates that the conditions were favourable for its development; or that the parent rock contained leucoxene which it passed on to the soil. That most leucoxene seen in soils is formed there is suggested by the fact that in rocks leucoxene does not usually occur as small rounded grains, but as angular replacements of ilmenite, and these have very seldom been seen in soils even when their presence would be expected.

It is interesting to note in this connection, that at certain pH values many properties of soil constituents are defined. (Prescott, 1931, p. 25.) Precipitation of aluminium silicate takes place at pH 4, and precipitation of $Fe(OH)_2$ at pH 5.5. Silica gel will form between pH 5.5 and pH 8.0. "The solubility of alumina as affected by reaction is probably of great importance in determining the progress of rock weathering. Only in extremely acid or extremely alkaline conditions would the complete break-down of the alumino-silicate nucleus be expected, and the presence of free alumina in lateritic soils indicates that conditions of high acidity probably prevailed at the time the laterite was in process of formation."

Titanic acid is somewhat similar in nature to silicic acid: both occur as colloidal solutions and form gels, so that one might expect a similar pH range for the precipitation of titania as for silica. It is known that from colloidal solutions of silicic acid within the soil opaline silica and finally crystalline quartz can form. Meta-titanic acid in granules has been observed in kaolins; these granules would crystallise as anatase or possibly rutile. The range for formation of titania gel may be very nearly the same as that for silica gel (pH 5.5 to pH 8.0), but from actual examples of crystallisation in situ (Brammall & Harwood, 1923) it appears that the pH would be lower, possibly pH 3 or 4. If leucoxene can occur authigenically in soils then the presence of lime would cause an increase of the pH, but if the titania gel has a considerable pH range, then the tendency to crystallise as anatase would probably be stronger than the tendency to unite with lime to form leucoxene. Abundant lime with a little titania gel would be more favourable for leucoxene formation, than abundant titania gel and a little lime. Soils with plentiful leucoxene have probably passed through a stage when the leaching of lime originally present was prevented. If the reaction was acid and the drainage good, then the lime would be leached out. In lateritic soils therefore, leached tropical soils, and podsols, it is to be expected that, other conditions being equal, there will be a smaller development, if any, of leucoxene than in more alkaline soils. But it must be remembered that ilmenite is a fairly stable mineral, and even with favourable conditions the change would be slow. Titanic acid for these reactions may also be derived from the disintegration of mica, hornblende, or titaniferous augite.

Iron solutions.—Another process of importance in soils and due to the climatic zone in which they occur is the transfer and precipitation of iron solutions. This is illustrated by the hard-pan or ferruginous B. horizon often found in podsols, which (in Australia) develop typically in sandy coastal regions. Mineralogical examination of such soils shows that there is a definite ferruginous band developed some distance below the surface. Often the iron is present in little grains of fairly high refractive index, referred in this paper to kaolinised material, possibly nontronite. Ferric hydroxide is the stable form in which iron is found in the soil. Prescott (1931, p. 22) states, "The downward movement of the iron (in podsols) may be affected in three possible ways: the solution of the iron in the ferric ionic state, the preliminary reduction to the ferrous state followed by solution, and the peptisation of the ferric hydroxide and its movement in the soil in this form. Such a colloidal solution would be held up by a clay illuvial horizon acting as a semi-permeable membrane, or would be precipitated in the lower horizons or at ground water level." "The critical soil reaction would be about pH 3 for the solution of ferric hydroxide, pH 5.5 for the solution of ferrous hydroxide, and pH 6.6 for the peptisation of colloidal ferric hydroxide." Humus and colloidal silica may act as peptising agents. Whatever the cause of the transfer and deposition of iron oxides, it can be recognised microscopically in many soils, *e.g.*,

those from the Hundred of Kuitpo, S. Australia, and without further examination it is recognised that leaching as seen in a typical podsol has taken place.

That some soils contain magnetite and others ilmenite may in part be due to differences in parent material, but weathering has also some influence. Soil formed by the breaking down of a hard lateritic formation, such as those found in parts of the interior of Western Australia, are more likely to contain magnetite than are some other soils, because the original iron constituent will have become dehydrated by continual baking during the long dry summers.

Alunite formation.—A process which has been recognised in some of the mallee soils of Western Australia is the formation of alunite at depth (H. Bowley, Annual Report of the Chemical Branch, Mines Dept. W.A., 1932, p. 8). In a typical occurrence at Lake Brown the surface soil is salty. Salt in Australian soils is thought by Prescott (1931, p. 16) to represent the balance between cyclic salt brought inland by wind and rain, and that removed by drainage under conditions of normal rainfall. Acid conditions appear to be necessary for alunite formation, as it has been found at depth where the pH is low. The parent material most probably supplies the potash. Aluminium silicate is precipitated at pH 4.0 and this may have something to do with the occurrence. It is possible that the necessary sulphate may have been supplied by gypsum or other salts, more complex, in times of heavy rainfall, in the circulation of ground water. Alunite grains have not been recognised in soils, and indeed, would not be expected where the samples have been subjected to acid treatment. The Lake Brown soils, and others similar mineralogically, contain small grains most probably of clay material which differ from those found in soils developed in other soil zones.

The following study of the mineral grains identified in a series of fine sands of soils from Western Australia, South Australia, Tasmania, Java, Borneo, and Japan is offered as a contribution to the study of the processes outlined above. The work was done at home (in Bunbury) in 1932, and was revised in the early part of 1934 at the Department of Geology, University of Western Australia, while holding a Hackett Research Studentship.

The chief objects of this investigation were to find out if there is any relationship between the climatic conditions during soil formation, and the changes which some of the less stable primary soil minerals undergo, and whether a study of the occurrence of secondary soil minerals would be of any assistance in tracing the history of a soil, or indicating the climatic conditions of its formation.

The investigation followed similar lines to that already completed (Carroll, 1931-32).

II.—SOURCES OF THE MATERIALS.

The fine sands of soils from the Hundred of Kuitpo, South Australia; King Island, Tasmania, and two samples from Japan were kindly sent over from the collection of the Waite Institute, Adelaide, South Australia, by Professor J. A. Prescott.

A series of red clay soils from Java and Borneo were kindly given to the Department of Geology by the late Professor J. van Baren, Agricultural University, Wageningen, Holland.

The samples of Western Australian soils described in this paper were obtained through the courtesy of Dr. L. J. H. Teakle, Department of Agriculture, Perth, and Mr. B. L. Southern, Government Chemical Laboratory, Perth, Western Australia

In the tables the samples are numbered, and the depth of sample given. The sample numbers of the Eastern States soils refer to the catalogue of the Waite Institute, Glen Osmond, South Australia; those of the West Australian soils to the catalogue of the Government Chemical Laboratory. The East Indian sample numbers are those given by the Museum, Geological Institute, Agricultural University, Wageningen, Holland.

III.—METHOD OF EXAMINATION.

Most of the samples used in this investigation were the fine sand residues from mechanical analyses (0.2 — 0.02 mm. International Mechanical Analysis standard). As the red clay soils from Java and Borneo, and the soils from Manjimup, Western Australia, had not been analysed mechanically, the following procedure was adopted in order to obtain the fine sands required for microscopic examination: the samples were deflocculated by boiling with water to which a little ammonia had been added, and the silt and clay fractions decanted and allowed to settle in tall beakers, to which a little acid was added to hasten the sedimentation. Silt and clay were very difficult to remove from the tropical soils, while coarse sand and gravel were inconspicuous. The results of this rough mechanical analysis for the tropical soils were:—Silt and clay about 90 per cent., coarse and fine sands about 10 per cent. These soils were very ferruginous, and, owing to the high clay content, when dry formed hard lumps.

The fine sands of all samples were cleaned by boiling gently with a 5 per cent. solution of oxalic acid, and panned to reduce the bulk before separation into light and heavy fractions with bromoform (S.G. about 1.8). Panning alone was found to give a sufficiently clean separation into two fractions for microscopic examination of many of the fine sands, e.g., those from King Island Where the heavy fraction was fairly large in amount, magnetite was tested for with a magnet, and was removed before a mount was made in clove oil (refractive index, 1.53).

In order to obtain an accurate idea of the mineralogical composition of the fine sands, the number of grains of each species present in each mount of heavy fraction was counted, this being facilitated by using a mechanical stage and a micrometer eyepiece. The percentage composition of the heavy fractions was obtained, and from these figures the following frequency numbers were allotted to the species according to the method used by the Burmah Oil Company (Evans, Hayman, and Majeed, 1933).

Frequency.	Approximate Percentage.
8+	90—100
8	75—89
8—	60—74
7+	45—59
7	35—44
7—	28—34
6+	23—27
6	18—22
6—	14—17
5	7—13
4	4—6
3	2—3
2	1—2
1	½—1
1*	One grain only.

Although the percentage and actual numbers of grains counted are interesting, the frequency numbers are more easily followed in the tables.

If there was only a small amount of heavy fraction, it was all mounted, *e.g.*, Burbrook sand, while if there was abundance of material one mount was made, and the remainder used for determination of refractive index, etc.

The mineral grains were identified by the usual optical methods, and compared with a standard set of detrital grains.

IV.—MINERALOGY OF THE FINE SANDS.

A.—SOILS FROM PODSOL ZONES.

(i).—HUNDRED OF KUITPO, SOUTH AUSTRALIA.

The Hundred of Kuitpo is situated in the hills east of Adelaide, Lat. 35° 12′, Long. 138° 48′. The soils of the southern part of the Hundred were mapped by Taylor and O'Donnell (Trans. Royal Soc. S. Australia, 1932). The main features of the district are "the sharply-defined quartzite ridges forming the eastern and western boundaries of the Hundred, and the intensely dissected, steep-sided, flat-topped remnants of the ancient peneplain which originally covered the whole area between the bounding ranges." The annual rainfall is 35 inches, 25 of which fall between April and September. The following descriptions of the soil types are taken from Taylor and O'Donnell.

Meadows clay loam: An alluvial dark grey to black soil overlying heavy clay. Occurs only in valley bottoms.

Meadows sand: A grey to white sand or coarse sand overlying yellow heavy clay.

Myponga sand: A deep podsolised grey to white sand overlying yellow sand over sandstone. A distinct typical coffee-brown layer is often present between 30-60 inches.

Kuitpo gravelly, sandy loam (lateritic): Grey to yellow sandy loam, with varying content of ironstone gravel over yellow friable clay with ironstone gravel.

Burbrook sandy loam: Grey sand or sandy loam over buff loam or friable clay over rock (schist and quartzite). Frequently stony and shallow soil.

Kondoparinga loam: Brown loam, sometimes moderately high in silt over phyllites.

KUITPO GRAVELLY, SANDY LOAM (lateritic origin).

Samples 146 (0-7″); 147 (7-14″).

Light fraction.—The light fractions consist principally of angular to sub-angular grains of quartz with small inclusions of apatite, zircon, and gas bubbles. Felspars and spicules* were found in 147 but not in 146. The 0-7″ horizon contains a little kaolinised material which is more plentiful in the 7-14″ horizon where it has a yellowish brown colour and a "fluffy" appearance. These grains may be nontronite in part. (?)Nontronite is the

* For this and subsequent references see Carroll, 1931-32.

name given to certain small secondary grains found in the fine sands. These grains may be irregular or rounded, and range from practically colourless to bright brown, and from opaque to translucent. Some will give faint interference figures. When boiled in HCl or oxalic acid the brown colour is removed, but the grains are not wholly destroyed. Malachite green stains them readily, and boiling in KOH (20%) will often dissolve the grains. The refractive index is usually about 1.55, often slightly higher, rising to 1.59.

Heavy fraction.—Iron and titanium minerals make up the bulk of the heavy fractions. Of the subordinate minerals, the more interesting are zircon, tourmaline, and sillimanite, the latter accounting for 10% of the heavy fraction in sample 146.

Samples 1932 (0-12″); 1933 (12-24″); 1934 (24-30″).

Light fraction.—The light fractions consist mainly of quartz grains. In the surface 12″ the grains are small, angular, clear and colourless but in the 12-24″ horizon the grains are larger and more rounded, while in the lowest sample the grains are large and about half round. Some of these contain beautiful sagenite webbing of rutile. Kaolinised material, possibly nontronite, is much more abundant in the lower horizons than at the surface. These grains give colour to the fine sand and are not appreciably altered by treatment with weak acid. Felspar is very scarce, a few grains doubtfully referred to orthoclase were found in 1932, but not in the other light fractions of this profile. Muscovite was quite commonly found in the light fractions; because of its flaky character it failed to separate with the other heavy minerals. Spicules were abundant in 1932, common in 1933, but very scarce in 1934.

Heavy fraction.—All the samples have an abundance of heavy minerals. 1932 has hundreds of grains which appear to be ilmenite altering to rutile. The ilmenite grains are black and opaque with a metallic lustre; rutile is found in bright reddish patches on the surfaces of these grains. This ilmeno-rutile is less well developed in 1933 and 1934. The principal subordinate minerals are zircon, in small, rounded, prismatic grains; and tourmaline in pinkish-brown, broken and irregular crystals, with a few grains of sillimanite and kyanite.

Samples 1846 (0-7″); 1847 (10-14″); 1848 (14-21″); 1849 (21-27″).

Plate IV., Fig. 1.

Light fraction.—Quartz in clear, colourless, angular to sub-angular grains makes up the bulk of the light fraction. The surface sample contains a few rounded grains, but there is less in the lower parts of the profile. Brown iron ore (? hematite), rutile (?), apatite and gas bubbles were found as inclusions in the quartz, but most of the grains were free from inclusions. Felspars were not found in the lower parts of the profile, but a few grains were found in 1846, one showed faint twin lamellae, while another had microcline twinning. Kaolinised material was common in the surface layer and increased with depth. In 1849 it was abundant in small, bright yellow grains, the refractive index of which was about 1.59. It has been referred to (?) nontronite. Muscovite was fairly common.

Heavy fraction.—In the heavy fraction, as in all the samples of this gravelly, sandy loam, ilmenite, rutile and leucoxene are the principal minerals. Subordinate minerals are not plentiful, and differ from those already described only in the abundance of mica.

BURBROOK SANDY LOAM.

This soil is probably derived from schists or quartzites. Samples 148 (0-9″); 149 (9-13″). Plate IV., Fig. 2.

Light fraction.—Quartz is the predominating mineral of the light fraction; it occurs in clear, colourless grains of two distinct sizes:—large half-round to sub-angular grains, and smaller angular grains. In the lower sample there are fewer rounded grains than in the surface soil. Inclusions are scarce, only a few minute rods of apatite being found. Felspar is scarce, only a few grains of orthoclase being found. Kaolinised material is not plentiful, but spicules were fairly numerous. Small crystals of zircon, tourmaline, and biotite failed to separate with the rest of the heavy minerals.

Heavy fraction.—Iron and titanium minerals make up the bulk of the heavy fraction. There are two varieties of rutile:—one, reddish brown, was probably formed in situ from ilmenite; the other is yellowish brown. The grains tabulated as limonite are possibly partly rutile, or a mixture of decomposed iron and titanium compounds. Tourmaline and zircon are the most plentiful of the remaining minerals, while biotite failed to separate and was left with the light minerals.

MYPONGA SAND (over sandstones).

Plate IV., Fig. 3. Samples 227 (0-9″); 1924 (0-20″); 1925 (20-30″).

Light fraction.—The light fraction, consisting mainly of quartz, makes up the bulk of the fine sand. Many of the quartz grains are rounded in 227, well rounded in 1924, but angular for the most part in 1925. The angular grains are small and clear. The rounded grains of 1925 are much larger than the angular ones, and are often dull and clouded. Zircon, rutile, and (?) apatite were found as inclusions. Untwinned felspar, probably orthoclase, was found in 227, but not in the other two samples. Kaolinised material was found in 1925 as dull yellowish-brown translucent grains, some of which gave a faint biaxial figure. These grains were not plentiful.

Heavy fraction.—In each sample there is only a small amount of heavy fraction, about half of which is accounted for by the iron and titanium minerals. Tourmaline and zircon are interesting, as they occur in large, rounded grains, showing that they have suffered much wear. A few grains of andalusite, kyanite, sillimanite, epidote, and garnet were also found.

MEADOWS SAND (alluvial).

Plate IV., Fig. 4. Samples 1917 (0-12″); 1918 (12-30″); 1919 (30-42″).

Light fraction.—Quartz is the principal mineral of the light fraction, and occurs in small, fresh-looking, angular fragments, and in larger, round to sub-round grains containing inclusions of rutile (sagenite webbing), zircon and (?) apatite. The majority of the grains are angular. Felspars are scarce and occur in very small fragments. Kaolinised material was found in 1918 and 1919 and had a similar appearance to that already described. Spicules were plentiful in the first horizon, numerous in the second, and but sparingly present in the third horizon.

Heavy Fraction.—The heavy fractions are fairly abundant and present some interesting features. In the first sample (0-12″), rutile and ilmenite are the predominating minerals, and leucoxene is subordinate. In the second sample (12-30″), pure ilmenite is less plentiful than rutile and "limonite."

The term "limonite" is reserved in this description for grains which cannot readily be classed as ilmenite, leucoxene, rutile or mixtures of these. In the third horizon (30-42″), ilmenite and rutile are about equal in amount, with about half as much leucoxene. In addition to "limonite" there is a "flood" of semi-opaque, alteration product, which has the same features as noted in the light fraction. Of the accompanying minerals, sillimanite is the most plentiful, being followed by tourmaline and zircon, the latter in small, rounded prisms showing much wear. A few grains of anatase, epidote, biotite, kyanite, ? andalusite, and augite were also identified.

MEADOWS CLAY LOAM (alluvial).

Samples 1929 (0-4″); 1930 (4-20″); 1931 (20-36″).

(Plate IV., Fig. 5.)

Light fraction. Quartz makes up the bulk of the light fraction and is present in clear, angular to sub-angular grains, with a fresh and completely broken appearance. In the second horizon (4-20″) the grain size is larger, but in the third is similar to the first. Felspar was not found in the surface sample, but a few grains were identified in the lower horizons. The grains were untwinned, but owing to the smallness of their size cannot be referred with certainty to a particular species, though they are probably orthoclase. Kaolinised material is present in the lower horizons, and is similar to that already described. Spicules and allied small organic remains are very common, and make up an appreciable part of this fraction in the surface sample; they are less plentiful in 1930, and only sparingly present in 1931.

Heavy fraction.—The heavy fraction is small in amount and the iron and titanium minerals make up less than 50% of the heavy minerals. Muscovite and biotite are prominent in this soil, making an important distinction between the Meadows clay loam and the Meadows sand. Biotite is the most plentiful mineral of the 20-36″ horizon, while muscovite is common throughout the profile. Tourmaline and zircon are the most conspicuous of the remaining grains identified. Tourmaline occurs in very small, grey prisms, often with one end broken. The tiny crystals have the appearance of having been inclusions in other minerals, *e.g.* quartz, from which they have recently been released. The zircon crystals seem to have had the same origin. A few grains of anatase, kyanite, hornblende, and sillimanite were also identified. The samples were difficult to examine on account of the extremely small size of the grains.

KONDOPARINGA LOAM

(over micaceous schists and phyllites).

Samples 1926 (0-2″); 1927 (2-9″); 1928 (9-15″).

(Plate IV., Fig. 6.)

Light fraction.—Quartz makes up the bulk of the light fraction. It is in very small, clear, angular to sub-angular fragments. In the third sample (9-15″), larger, more rounded grains occur as well as the small angular fragments. Inclusions seen were minute zircons, and tourmalines similar to those found in the heavy fraction. Felspar is scarce and occurs in small, angular grains of a pinkish colour, only to be distinguished from quartz by the refractive index. It is probably orthoclase. Spicules were very abundant throughout the profile.

There are three kinds of mica present:—muscovite, biotite, and a greenish-yellow mica which may be altered biotite. The micas, owing to their small size and flaky character, failed to separate with the other heavy minerals. Kaolinised material was not identified in this soil.

Heavy fraction.—The most noticeable feature of this soil is the scarcity of heavy minerals. The greater part of the heavy fraction is made up of ilmenite and rutile, the latter having a greater development than leucoxene. Anatase is conspicuous in the second and third horizons in small, gray-blue prisms. The grain size is, on the whole, very small, although some of the ilmenite grains are large. The appearance of the mounts are similar to those of the Meadows clay loam. Of the remaining minerals, sillimanite, garnet, and mica are conspicuous, while some samples contain a few grains of kyanite, hornblende, and epidote. Tourmaline and zircon occur as in the Meadows clay loam.

KING ISLAND, TASMANIA.

King Island is situated in Bass Strait between Victoria and Tasmania. Lat. S. 39° 50′, Long. 144° 0′ E. A soil survey has been made by Stephens and Hosking (Bull. 70, C.S.I.R. Australia, 1932). Eight types of soil were identified, the fine sands of three of which, the Pegarah fine sandy loam, the Naracoopa sand, and the Lappa sand, are described below. The rocks of the island include sediments (Recent, Tertiary, and early Palaeozoic), while there is a small development of granite, dolerite, and basalt. The sand dunes on the west side of the island are an important feature.

The *Pegarah fine sandy loam* is associated with the plateau of the island, and it originally carried sclerophyll forest. It is considered to be a residual soil from the country rocks which are slates and schists.

The *Naracoopa and Lappa sands* are closely connected with the Pegarah type. The Naracoopa sand occurs on the inland dune formations at high levels on the eastern coast. It is known as "Fernbank" as it carries thick growths of bracken. The Lappa sands are found in troughs between the dunes (Naracoopa) and the Pegarah tablelands. It is thought that these sands are associated with and derived from the extensive denudation of the Pegarah fine sandy loam. The drainage of the Lappa sand is poor.

PEGARAH FINE SANDY LOAM.

(Timber type (?) over parent rock.)

Samples 2225 (0-6″); 2226 (6-13″); 2227 (13-45″).

Light fraction.—Quartz is the principal mineral of the light fraction. The grains are clear, colourless, angular to sub-angular, and show little evidence of transport, although a few larger rounded grains are also present. Many grains have a broken, pitted appearance, while others are cloudy. Minute zircons, tourmalines, iron ores, (?) apatite, and sillimanite rods were noted as inclusions. Felspar was fairly plentiful in the surface sample, but not so abundant in the other horizons. It has been referred to orthoclase as the refractive index is just below 1.53, and the grains are untwinned. A few grains were identified as microperthite. All the felspar grains were fresh and unclouded. Kaolinised material was found only in the third horizon (13-45″). These grains are pale yellow-brown to almost colourless, and are probably similar to those described from the Kuitpo samples. Spicules are sparingly present throughout the profile, though there are not many in the lowest horizon.

Heavy fraction.—The heavy fraction is very plentiful and characterised by a "flood" of ilmenite (over 70 per cent.). Leucoxene is a little more abundant than rutile, but both are very subordinate to ilmenite. There are only a few grains of magnetite. Andalusite, tourmaline, and zircon are the most abundant of the remaining minerals. Andalusite occurs either in prismatic grains or broken fragments, the larger grains being very pleochroic in 2226. Tourmaline occurs in sharp-edged, brown prisms with many inclusions, rounded basal sections and broken fragments. The zircons are in fairly large, stout, prismatic crystals, some quite clear, others zoned and with many inclusions. Garnet is interesting because several perfect, dodecahedral crystals were found, particularly in 2227 (13-45″). A few grains of muscovite, anatase, sillimanite, kyanite, and epidote were also found.

NARACOOPA SAND.

(Fernbank types over deep sand, well drained.)

Samples: 2232 (0-13″); 2233 (13-60″); 2234 (60-80″).

(Plate V., Fig. 7.)

Light fraction.—In the light fraction the quartz grains vary from subangular to well-rounded; the grains are very uniform in size, and many are equidimensional. There are a greater number of rounded grains in the second and third horizons than in the surface soil. The only inclusions found were rutile and gas bubbles. The appearance of this fraction is very similar to that of the Esperance sands (Carroll, 1931-32). Grains with a fresh appearance and refractive index slightly below 1.53 have been identified as orthoclase, acid plagioclase, and mirocline. In 2233 the felspar grains are more rounded than in the surface soil, but are less rounded than the quartz. Kaolinised material was found in the second and third horizons as small, yellowish brown grains. Spicules were not found.

Heavy fraction.—The heavy fraction is very large, and consists of over 50 per cent. of ilmenite. Leucoxene and rutile are present in about the same amounts, though leucoxene is slightly less than the rutile, which is the reddish brown, prismatic variety. Zircon is very conspicuous, and makes up 25 per cent. of the heavy fraction in the surface sample, but rather less in the other horizons. It occurs in several distinct habits:—well-worn, prismatic grains; prismatic-pyramidal crystals; and rectangular-prismatic crystals. Associated with zircon are grains of an appearance somewhat similar to the first zircon type, but with a slightly pitted surface and a pale green colour. These grains have been referred to monazite. The few remaining grains are similar to those already described (from the Pegarah fine sandy loam), with the exception of kyanite, which is in well-worn grains in contrast to the fresh andalusite. Garnet is in irregularly fractured fragments of a pale, pinkish brown colour.

LAPPA SAND.

(Plain type—over deep sand, poorly drained.)

Samples: 2241 (0-9″); 2242 (9-38″); 2243 (38-50″); 2244 (50-80″).

Light fraction.—In the light fraction, quartz predominates in angular to half-round grains. Most of the grains contained no inclusions, but those noted were, rutile, iron ores, tourmaline, zircon, and gas bubbles.

The grains were more angular towards the base of the profile, and cloudy grains were fairly common. Felspar was inconspicuous in the surface soil, but present in the lower horizons as small, clear, angular grains, some of which showed faint twin lamellae. A few grains of muscovite were found in the lower horizons, and spicules were sparingly present throughout. A small amount of kaolinised material was found in the 9-38″ horizon.

Heavy fraction.—The heavy fraction is large in amount and similar to the types already described, but it differs from these in the greater development of leucoxene. In the first horizon it is twice as plentiful as ilmenite, and in the other horizons it is about equal in amount to ilmenite. Rutile diminishes in amount. Zircon is very plentiful in the habits already noted. Tourmaline is very abundant, brown primatic grains predominating, but there are also large numbers of irregular blue grains, while many grains have patchy colours, pink and brown, or blue and brown. Andalusite is mostly in little broken fragments, unclouded, and faintly pleochroic. A few grains of kyanite, sillimanite, garnet, epidote, and anatase were also found, but have no significant features.

The microscopic examination shows that these three types of soil appear to have been derived from the same or similar parent material.

MANJIMUP, WESTERN AUSTRALIA.

(Lat. 34° 16′, Long. 116° 8′).

I. *Principal timber, Karri (E. diversicolor).*

1473	0—9″	top of hill	(G. F. Coomb's holding.)
1474	9—18″	,,	
1475	0—9″	one-third down hill	
1476	9—18″	,, ,,	
1477	0—9″	two-thirds down hill	
1478	9—18″	,, ,,	
1479	0—9″	edge of swamp	
1480	9—18″	,, ,,	

The soil (Karri type) is deep reddish-brown in colour, because of a heavy ferruginous coating on the grains of the fine sand. It is a clay loam, the plentiful clay particles being difficult to remove during sedimentation in tall beakers.

Light fraction.—Quartz is the main constituent of the light fraction, but the grains are much obscured; when fairly clear, they are found to be rounded to sub angular, with few inclusions. On going down hill the ferruginous (?) limonitic coating becomes denser, but at the edge of the swamp (1479) the grains are much cleaner. Orthoclase and plagioclase are present in some samples, but are difficult to determine. Large angular grains of kaolinised or sericitized felspar were found in 1475, and in 1476 there were a few grains of plagioclase, possibly labradorite. (?) Nontronite is scarce; it occurs in small grains, some of which are reddish-brown while others are much paler. The greatest number of these grains were found in samples from two-thirds down hill (1477 and 1478). Spicules were fairly plentiful throughout.

Heavy fraction.—All the samples contained an abundance of heavy minerals. Most of the ilmenite grains, which make up over 90 per cent. of each heavy fraction, were covered with ferruginous material, most probably limonite. This is of a bright reddish-brown colour, and when the grains are heated in a closed tube water is given off, and the grains change from brown to black. Before heating very few grains would respond to a magnet, but afterwards about half were readily removed in this way. Leucoxene is not abundant in any of the samples, suggesting that the black mineral grains are magnetite rather than ilmenite, but it is difficult to draw the line between dark-coloured leucoxene and pale limonite. Zircon is the only other mineral of any importance. It occurs in small, rounded, prismatic crystals, often brown in colour. A few grains of rutile and tourmaline were found in some of the samples. At the edge of the swamp (1479 and 1480) the minerals indicate that there is a slight mixture with the Red Gum type found on the next hillside, and described below.

II.—*Principal timber, Red Gum (E. calophylla).*

1481	0—9″	edge of moist land.	(H. C. Barnsby's holding.)
1482	9—18″	,,	
1483	0—9″	top of hill.	
1484	9—18″	,,	

Plate V., Fig. 8.

The soil (Red Gum type) is much more sandy than the Karri type and is light yellow in colour. The clay and silt fractions are small in amount, the soil being a sand or sandy loam.

Light fraction.—Quartz is the predominating mineral of the light fraction. Large sub-angular to round grains are the most common; inclusions are not plentiful, but some grains have "wavy" extinction. At the top of the hill (1483 and 1484) the grain size is somewhat smaller and all the grains are angular, except some of the smallest, which are round, suggesting that these have been subjected to a certain amount of wear by transport. Felspar is present but difficult to distinguish from quartz. Plagioclase was present in 1841, but orthoclase was not identified. Some of the more obscured grains may be partially kaolinised felspar. (?)Nontronite is present; it is more plentiful at the top of the hill (1483 and 1484) than at the bottom. The obscuring material of these samples is of a dull yellowish grey colour, and not nearly as "heavy" as in the Karri type.

Heavy fraction.—The heavy fraction is interesting since, in contrast to the Karri type, it contains only about 40 per cent. of ilmenite. Leucoxene is plentiful, and zircon is conspicuous, for in the first sample (1481) it makes up about 40 per cent. of the heavy fraction. It is accompanied by kyanite, is worn cleavage fragments, rutile, tourmaline in broken, greyish-blue fragments, bright blue grains and brown to green crystals: garnet, amphibole, epidote, and sillimanite. Zircon is in worn prismatic crystals, mostly of a brownish colour, and with few inclusions. Many of the more elongated grains resemble kyanite on first sight, but most of the grains are stumpy, and some are broken.

From the above descriptions it will be seen that there are two distinct types of soil, both mineralogically and in the field. The Karri type may be a weathered and broken down laterite, which was originally formed over basic rocks. The Red Gum type, on the other hand, is much more quartzose, and may have been derived from an acid granite or a pegmatite, but the presence of a fair amount of kyanite suggests a metamorphic parent rock.

B.—TROPICAL SOILS.

(i).—JAVA.

(a). *Profile of volcanic material*, collected near volcanoes, Salak, about 20 miles south of Buitenzorg (Lat. 6° 30′, Long. 106° 48′).

156d.	surface soil, depth 1M.	*Plate V. Fig. 10.*
156c.	soil, 2nd layer.	
156b.	soil, 3rd layer.	
156a.	soil, 4th layer.	*Plate V Fig. 9.*

Light fraction. The light fraction consists principally of kaolinised material and kaolinite, with subordinate quartz and felspar. Kaolinite is most plentiful at the base of the profile (156a) and is interesting as it occurs in crystalline aggregates as illustrated by Ross and Kerr (U.S.G.S. Prof. Paper 165—E). The grains are of a pale yellowish-gray colour, slightly pleochroic, and vermicular. Each grain is made up of numerous tiny fibres, which are parallel to each other. A typical grain was 0.166 mm. long and 0.083 mm. wide. The interference colours are reds and yellows of the first order, and the extinction is practically parallel to the length of the small fibres. Other grains of kaolinite occur in flat plates, sometimes nearly hexagonal. Kaolinised material, possibly nontronite, is very abundant. It is yellowish brown (156a) but becomes darker towards the surface (156d). It is semi-opaque, but some grains are cryptocrystalline and have weak double refraction. *Felspar* is more plentiful than quartz, with which it may easily be confused. It is found in angular, clear grains with refractive index slightly above that of Canada balsam, and may be referred to labradorite. In the surface sample the felspar is present in large irregular grains with "pockets" of brownish, kaolinised material. Similar grains have been illustrated by J. van Baren (1928, Plate IV., Fig. 18). *Quartz* subordinate to plagioclase, is in clear, colourless, angular to rounded grains. An interesting feature is the present of a few euhedral crystals, practically free from inclusions, except for a few gas bubbles. In sample 156c there are more rounded grains than in the other samples. *Chalcedony* was found in small amounts throughout the profile, but is most plentiful at the base. It occurs in small rounded to angular grains with typical spherulitic extinction. It tends to remain with the heavy minerals.

Heavy fraction.- Heavy minerals are abundant throughout the profile. Magnetite and ilmenite are the most conspicuous. Most of the magnetite was easily removed with a magnet, but some remained in the mounts as square or dodecahedral crystals. It was often difficult to distinguish between the remaining magnetite and ilmenite. Leucoxene and rutile are feebly developed, but hematite and mica are noteworthy. Zircon is scarce,

only 40 grains being found in 35 full traverses. It occurs mostly in small worn prismatic crystals, but larger grains are sharp edged and of a pinky-brown colour and quite clear. The surface sample (156d) differs from the other parts of the profile in the presence of hypersthene. After removing the magnetite, hypersthene makes up about a fifth of the heavy fraction. It occurs in large brownish green, pleochroic prisms and broken fragments, often with inclusions of magnetite or ilmenite (see Plate V., Fig. 10). The whole appearance of the heavy fraction of 156d is altered by the presence of hypersthene, and differs considerably from that of the other heavy fractions of this profile.

Euhedral quartz, magnetite, prismatic pyroxenes, and felspars often with kaolinitic inlets (representing the original glassy matrix) are characteristic features of volcanic materials, even when combined in deep sea deposits. (C. S. Ross, Amer. Assoc. Petrol. Geol. vol. 12; Report of the Challenger Expedition, Deep Sea Deposits, Plate 27, Fig. 4, also numerous examples in the text.)

(b) *Profile of volcanic material* collected away from recent volcanoes Djasinga, south of the road Rangka-bitoen-Sadjina, N.W. of Buitenzorg (Lat. 6° 30′, Long. 106° 48′), Java.

Samples 993b, (0-30 cm. surface soil); 993a, (30 cm. subsoil).

Light fraction.—Kaolinised material and felspar are present in about equal amounts in the light fraction. Quartz, (?)nontronite and chalcedony are subordinate in amount. The kaolinised material is of a pale yellow colour and has a "felted" surface suggesting that mica was the original mineral. A few grains that are clear and translucent may be referred to (?) nontronite. Many felspar grains have a clouded surface due to the development of weathering products. The felspars present are probably two varieties of plagioclase: labradorite, and a more acid member, possibly andesine. The grains are angular and clear. Quartz is mostly in angular grains, many of which are euhedral; some of these contain liquid inclusions. Chalcedony is noticeable in the mounts on account of its light pinky colour and low refractive index, and is more plentiful in the subsoil than the soil. Micaceous aggregates are fairly plentiful as small, rounded grains, possibly derived from the weathering of the felspar. Spicules, rather large and stout, are fairly plentiful.

Heavy fraction.—The heavy fraction, large in amount, consists mostly of ilmenite, with much less magnetite than the surface sample of the (a) series described above; or, at least much less could be removed with the magnet. The only prominent minerals remaining are hypersthene and zircon. Hypersthene is much more plentiful in the surface soil (993b) than in the subsoil, from which it may have been removed or altered by the soil solution. Zircon is scarce; it occurs in small, worn, prismatic grains. Leucoxene and rutile are not conspicuous; leucoxene is in excess of rutile. A few grains of anatase were found in the subsoil (993a).

(c) *Limestone soil*, 1 Km. S.W. of Toeban, Rembang (Lat. 6° 45′, Long. 111° 24′), East Java.

Samples 1000c. (0-15 cm.); 1000b. (15-105 cm.).

Light fraction.—Brownish ferruginous material makes up the bulk of the light fraction. It is semi-opaque and apparently a decomposition product mixed with iron oxide (? ferric hydroxide). When a few grams of the parent rock were dissolved in HCl, similar grains were found in the residue. It gives the colour to the soil, for the subordinate quartz is clear, colourless, and little encrusted with iron compounds. The refractive index of this material is fairly high. A possible explanation is that it is limonite formed by alteration of glauconite, but no grains of the latter mineral were found in the rock, which was a white, dense, unfossiliferous limestone. The quartz grains are mostly angular, but a few are round. Inclusions of gases and rutile were found. In 1000c. the grain size is rather smaller than in 1000b. Felspars seem to be absent, but could be mistaken for quartz. Their presence is suggested by some slightly kaolinised grains. A few grains of chalcedony were also present.

Heavy fraction.—The heavy fraction is made up principally of iron ores. Magnetite is very plentiful, while leucoxene and rutile were not conspicuous. "Limonite," which is possibly a very dark variety of (?) nontronite as it is semi-opaque, and has much the appearance of members of this series, is very strongly developed in the subsoil (1000b.), but there is only a small amount at the surface. The remaining minerals include zircon, hypersthene, epidote, hornblende, (?)augite (possibly hypersthene), sillimanite, and kyanite, the latter in very worn grains. Zircon is in very small worn, brownish prisms, one or two acicular crystals were seen, but the usual type is broken grains. Epidote is rather pale and colourless. Hornblende occurs in typical brownish-green cleavage fragments.

ii.—BORNEO.

Samples 930b. Gabbro soil (surface), Martapoera, Lat. 3° 29′; 1135b. Gabbro soil (surface), Martapoera, Long. 115° 0′.

Light fraction.—In 930b. felspar, probably labradorite, is the main constituent of the light fraction. It occurs in fresh, angular, somewhat rectangular grains and in more rounded grains showing kaolinisation. Where altered, the grains are yellowish-brown in colour and often well-rounded. Quartz and ferruginous material appear to be absent from this soil, but there is difficulty in distinguishing the quartz from plagioclase. "Limonite" (ferruginous material) covers practically all the grains of 1135b. and apparently little was removed by oxalic acid treatment. It is present in fairly large rounded grains, the cores of which may be kaolinised material or felspar. There are, in addition, a few grains of semi-opaque, micaceous material and a little chlorite.

Heavy fraction.—Although both are derived from gabbro, these fine sands differ very considerably mineralogically. In 930b. there is a small amount of heavy fraction which contains over 70% of iron and titanium minerals. Magnetite was not separated from the ilmenite. 1135b. contained a large amount of heavy minerals, about half of which were magnetite, the

ilmenite-limonite association being so strong that no traverses were made. In 930b. the abundance of pale to bright green epidote, which made up 20% of this fraction was noticeable. 1135b. contained, in addition to a few grains of leucoxene, fairly plentiful pyroxene of a pale green colour giving extinction angles between 42 and 47 degrees, measured from the long axis of the grains and parallel to the cleavage. The grains are non-pleochroic, and may possibly be referred to diallage or diopside. In 930b. leucoxene and rutile are feebly developed, and the remaining grains of the fraction consist of zircon, tourmaline, (?) amphibole, and garnet, which were hardly represented in 1135b.

Small pieces of the parent rocks were crushed to obtain the constituent minerals. 930 contained a little magnetite, plentiful pale green epidote, a little augite with high extinction angles, and a large amount of brownish decomposed material. 1135 consisted mainly of colourless augite, with subordinate, although fairly plentiful magnetite. The mineral grains remaining in the fine sand show how completely weathered the resulting soil is, when compared to the parent rock.

Soil from peridotite Bandjermasin, Lat. 3° 30′, Long. 114° 38′, Borneo.

Sample: 924c. (surface soil).

Light fraction.—The bulk of the light fraction is made up of small, angular to somewhat rounded grains of a felspar which has a fairly high refractive index, and is therefore plagioclase not more acid than labradorite. It is untwinned, and some of the clearer grains are almost euhedral. The smaller grains are fresh and clear, but the larger are cracked and often show incipient alteration to a yellowish material. Accompanying the plagioclase are grains of a yellowish material which perhaps represents the olivine of the parent rock. These grains are quite irregular, and often have a felted appearance, due, possibly, to the addition of iron compounds. In some grains small cubes of an opaque mineral (? chromite or magnetite) are embedded. The double refraction is very weak, and most of these grains are practically isotropic. A few spicules were found.

Heavy fraction.—The fine sand contains an abundance of heavy minerals, of which magnetite and ilmenite are the most prominent. After the removal of magnetite, the ores make up over 90% of this fraction. Leucoxene is plentiful, but only a few grains of rutile were found. Zircon is the only other abundant mineral: it occurs in fairly large prismatic crystals, capped by acicular pyramids, and is little worn. Some of the grains are irregularly fractured, and a few are quite small. A little epidote failed to separate and was left with the light fraction. Chromite was doubtfully identified microscopically, as opaque grains with brownish semi-opaque thin edges. This was confirmed with the blowpipe, the indication being strong, so that many of the ore grains are probably chromite.

The parent rock, when crushed, was found to contain little other than olivine. The olivine was clear, almost colourless and unaltered, and on weathering has given rise to the large amounts of opaque material in the soil. Possibly some of the clear grains thought to be felspar are actually quartz derived from the olivine by weathering in a situation of intense leaching. In basaltic soils in some parts of Australia olivine persists, so that the alteration is due to the climate under which the soil has developed.

Soil from andesite, Tanahamboengang, Borneo (Lat. 2° 5′, Long. 116° 15′).

Sample: 928b (surface soil).

Light fraction.—In the light fraction most of the grains are obscured by iron compounds, but where fairly clear are seen to be felspar (? labradorite). There are two sizes of grains, the larger from phenocrysts and the smaller from the groundmass of the parent rock. The larger crystals nearly all have a rectangular habit. Yellowish-green chloritic material is also present; it is slightly pleochroic, and one grain seems to be a pseudomorph after augite. Other grains are practically isotropic. Minute, brownish, isotropic material may be the remains of original interstitial glass.

Heavy fraction.—The heavy fraction consists mainly of magnetite with a little ilmenite. Leucoxene, probably mixed with limonite, is conspicuous, but rutile is practically absent. Of the remaining minerals, pale green to colourless augite is the most plentiful. It occurs in rather rectangular grains, some of which have inclined dispersion so that the extinction is not sharp. These grains are brownish and are probably titan-augite. Zircon and epidote are scarce, while there are a few grains of green hornblende.

The parent rock, when crushed, was found to contain abundant brownish-green hornblende, which has practically disappeared from the soil, probably being represented there by the ferruginous opaque grains. The rock was a hornblende andesite, with a little augite and felspars of two generations. The augite was able to persist in the soil on account of its greater stability under conditions of intense leaching.

C.—SOILS FROM THE MALLEE SOIL ZONE, W. AUSTRALIA.

(i.) NINGHAN.

Avon location 579. Lat. 30° 0′, Long. 117° 30′. Plate V., Fig. 11.

Samples:—1634 (0-3″); 1635 (3-12″); 1636 (12-27″); 1637 (27-46″); 1638 (46-72″); 1639/32 (72-75″).

Light fraction. The light fraction of the surface sample (1634) is made up of about 70% kaolinised material (? nontronite), while at the base of the profile (1639) the amount has dropped to about 15%. At the surface the nontronite is in small grains of a bright reddish-brown colour, but at 72″ it is pale yellow. All the grains are rounded and clearly of secondary origin. Associated with this mineral, and very similar in appearance, are numerous round grains usually of a light colour, and having spherulitic structure as shown by the polarisation. These grains may have the same composition as the ? nontronite. Grains of other minerals, *e.g.* ilmenite, often have a rim of this spherulitic material completely encircling them and the appearance under crossed nicols is peculiar. Quartz is present in fairly large sub-angular to half-round grains rather obscured with iron encrustations, and small angular, clear grains. The larger grains often contain good sagenite webbing of rutile. At the base of the profile (1639) the grains are much clearer than at the top. Orthoclase, plagioclase, and microperthite are fairly plentiful. Orthoclase occurs in small, pinkish "chips," and in sample 1639 is subordinate to acid plagioclase, possibly oligoclase. Twinned grains are in the minority. Some samples contain a few grains of opaline silica, and a few spicules were found in the surface soil.

Heavy fraction. The fine sand contains only a small quantity of heavy minerals. Ilmenite accounts for about 55 per cent. of the heavy fraction. Leucoxene is well developed, and there is over 30 per cent. of zircon. In the surface soil (1634) about 10 per cent. of crystallised, authigenous dolomite was found. The subordinate minerals include small amounts of colourless pale green amphibole, rutile, tourmaline, epidote, garnet, and micas (the latter in the lowest samples only). Zircon is in rounded, prismatic crystals, often yellowish brown in colour. Some grains are zoned, but inclusions are not plentiful. It is possible that some of these grains may be xenotime, as some have a "flat" habit consisting of the unit prism (a) capped by low pyramids. A chemical test for phosphorus is necessary for complete identification as xenotime.

(ii).—SOUTH GABBIN.

Avon location 20289. Approx. Lat. 31° 0′, Long. 118° 0′.

Samples: 1640 (0—2″); 1641 (2—6″); 1642 (6—12″); 1643 (12—24″); 1644/32 (24—36″).

Light fraction.—The light fraction of the fine sand is very similar to that at Ninghan, and consists of about equal quantities of quartz and kaolinised material (?) nontronite, with small amounts of acid plagioclase and orthoclase. Quartz occurs in clear, colourless, angular to sub-angular grains, the smaller ones being always angular. Inclusions are not plentiful, but the larger grains occasionally have sagenite webbing and minute zircons. All the grains are much less obscured than in the Ninghan samples. Kaolinised material occurs as in the Ninghan fine sand. This (?) nontronite gives the colour to the fine sand. Felspars occur in small, pinkish "chips" and are fairly plentiful at the base of the profile, but not so abundant at the surface. Orthoclase and an acid plagioclase are both present. The plagioclase is possibly oligoclase, while a few grains of microcline were found in some samples. Spicules were found in the surface sample only (1640).

Heavy fraction.—The heavy fraction is similar to that from Ninghan. The fractions contain about 60 per cent. of ilmenite and 20-30 per cent. of zircon. Dolomite is present in the first six inches. In this profile, as in many others, there seems to be a surface concentration of heavy minerals, which may be due to the action of wind in removing the lighter grains. A little sillimanite, kyanite, and garnet are among the subordinate minerals, which are present in about the same amount as in the Ninghan profile.

(iii).—LAKE BROWN.

Avon location 14343. Lat. 30° 50′, Long. 118° 28′.

Samples: 3577 (0—12″); 3578 (12—24″); 3579 (24—46″); 3586 (102—114″); 3587 (114—132″); 3588 (132—147″).

Light fraction.—The light fractions of this profile consist of 45-50 per cent. of quartz in clear, colourless grains, less than half of which are rounded. The angular grains are larger than the rounded ones in most samples. Orthoclase, in pinkish "chips," is plentiful, while there are smaller amounts of acid plagioclase, microcline, and microperthite. An interesting feature of

this soil is the development of small grains of secondary material with a low refractive index (1.49 to 1.50), suggesting that opaline silica is a constituent. These grains are pale yellowish-brown in the surface fine sand, but become more reddish in the 102-114" horizon, where they make up over 50 per cent. of the light fraction. These grains may possibly be montmorillonite (refractive index 1.516 to 1.493; Simpson, 1932), or beidellite. Below this horizon (3586) the grains have a slightly higher refractive index. Associated with these grains there are small quantities of (?) nontronite, in clear, yellowish-brown, rounded grains with refractive index over 1.56. The grains with the low refractive index may be isotropic, be weakly birefringent, or have spherulitic polarisation. The samples from the base of the profile are much paler in colour than those at the top, and the very definite ferruginous band at the 102-114" level suggests that from the bottom to this horizon may represent an original soil developed over granitic rocks, while above this there is a secondary transported soil, the parent rock of which was also granitic, but which was modified by an accumulation of calcium carbonate, possibly augmented by saline depositions from the lake.

The heavy fractions have already been described (Carroll, 1931-32, p. 135).

The profile at Lake Brown is interesting as at the surface the pH is quite high, while at depth, it falls to about 4. Dr. L. J. H. Teakle, Plant Nutrition Officer, Dept. of Agriculture, Perth, has found that the forest soils of the Mallee zone have a neutral or practically neutral surface, a calcareous B horizon, on an acid C horizon which often contains alunite. Alunite is developed at depth in the Lake Brown profile. Mr. H. Bowley, Assistant Government Mineralogist and Chemist, considers that alunite is associated with decomposing granite, the minerals of which supplied the necessary potash. The Lake Brown fine sand contains about 45 per cent. of quartz, with smaller amounts of orthoclase, plagioclase, microcline, microperthite, muscovite, biotite, and secondary minerals, orthoclase constituting 20 to 30 per cent. of the fine said. The kaolinised portion of the fine sand may be altered mica. Chalcedony and opaline silica also occur, and these indicate great alterations of the parent material. The mineral assemblage is thus suggestive of granitic origin. It has been considered, however (personal letter, Dr. L. J. H. Teakle), that these soils cannot have been derived from granite because the amount of lime in a granite would not be sufficient to form such a calcareous B horizon. There are not many analyses of granites from Western Australia, but one from Southern Cross whose mineral composition was quartz, microcline, orthoclase, oligoclase, biotite, muscovite, and kaolin, contains 0.55 per cent. of CaO (Geol. Survey W.A. Bull. 67). Most of the other granites analysed contain a greater percentage of CaO. One acre-inch of this Southern Cross granite would contain, on the average, nearly one and one-half tons of lime, which would accumulate if the drainage was poor. It seems possible, therefore, that the Lake Brown soil has developed from a granite similar to that at Southern Cross, from which place it is not far distant. The soil contains an excess of common salt, and there seems also to be an excess of sulphate in the 1-2 water extract analyses (Teakle, 1928-29). Alunite requires the sulphate ions for its formation; this is usually considered to be obtained from percolating surface waters charged with H_2SO_4 by the oxidation of pyrites. The occurrence of alunite is too general to admit of this explanation, and it is suggested

here that alunite in the soil may be formed in decomposing granitic rocks by the washing down of sulphate-bearing solutions, which were originally combined in saline waters as gypsum or some other salt.

The following table shows the mineralogical composition of the Lake Brown light fractions. The amounts of the various mineral grains present are expressed as percentages, which were obtained by traversing across the slides and counting the actual numbers of grains of different species.

Sample number.	3577	3578	3579	3586	3587	3588
Depth of sample	0″ to 12″	12″ to 24″	24″ to 46″	102″ to 114″	114″ to 132″	132″ to 147″
	%	%	%	%	%	%
Quartz	54*	44	50	16	49	54
Orthoclase	26	25	31	21	30	39
Plagioclase	2	P	P	...	2	P
Microcline	1	P	P	...	P	P
Microperthite	...	...	...	...	P	P
? Nontronite	0·5	...	...	9	17	5
? Beidellite	16	17	11	54	1	1·5
Chalcedony	...	13	8	...	...	...
Opaline SiO_2	...	P	P	...	...	...

* These percentages are approximate, the table having been simplified.
P = present.

(D).—LATERITIC SOILS.

(i).—WONGAN HILLS.

(W.A., Lat. 30° 45′, Long. 116° 35′.)

Samples: 5007 (0-8″): 5008 (8-18″); 5009/31 (18-+″).

Light fraction.—The principal mineral of the light fraction is quartz in clear, colourless, angular to sub-angular grains. Quartz is slightly more abundant in the subsoil than at the surface, and there are a greater number of rounded grains. Ferruginous material often obscures the grains in the lower parts of the profile. The inclusions noted were: rutile (sagenite webbing), zircon and (?) apatite (very minute rods). Felspars are nearly equal to the quartz in amount and are present in angular cleavage plates and worn clouded grains of a faint pinkish colour, which are readily distinguished from quartz by a lower refractive index. Many plates are rectangular, and some grains have albite twinning, but the majority are untwinned. Orthoclase and acid plagioclase are both present. Kaolinised material is pale yellow in colour and semi-opaque; some grains are finely crystalline. It is more abundant in the lower horizons than at the surface. Ferruginous material is darker in colour than the kaolin, and coats quartz and felspar grains. It gives colour to the fine sand. Spicules and other organic remains were found in the surface sample, but are not plentiful.

Heavy fraction.—The heavy fraction is abundant and contains over 50% of ilmenite. Leucoxene is fairly well developed, but only a few grains of rutile were found. Zircon, the most conspicuous subordinate mineral, occurs in two distinct types:—clear, prismatic crystals, often well worn; and brown grains partially obscured by pale, yellowish-brown, cloudy material. These

latter grains may possibly be xenotime, but chemical and spectroscopic work is necessary for complete identification. The remaining grains of this fraction are epidote, tourmaline, sillimanite, andalusite, hornblende, garnet, anatase, muscovite and biotite. A little kaolinised material remains with the heavy minerals. This may represent, in part, altered mica. The abundance of zircon and lack of ferromagnesian minerals suggests that the original rock was granitic. It is interesting to note that the mineral assemblage is rather similar to that obtained from crushed gneisses and granites of the Jimperding area. If this is a true lateritic soil one would not expect to find fresh felspar grains.

(ii).—TORIYA.

KAMI-AMADA.

Ishikawa prefecture, Japan, Lat. 37° 8′ N., Long. 140° 28′ E.

Plate V., Fig. 12.

These two red soils from the Bijozin Range were found to be interesting because, although considered lateritic, they were found to be feebly radioactive (Iimori, 1932). The chemical analyses show a large amount of silica, which is accounted for by the fact that the soils were derived from diorite or granite. ". . . . . . . these lateritic soils occurring in the Bijozan Range, Ishikawa Prefecture, Japan, were probably formed, in situ, from the diorite and granite by the action of sea water on the occasion of the recent transgression followed soon after the formation of Ochigata graben. The subtropical climate of summer-time in this region would also no doubt be favourable for the progress of laterisation."

The mineralogy of the two fine sands is interesting because of: (i) the large amount of mica; and (ii) the large amount of heavy fraction consisting principally of magnetite, most of which was easily removed before further examination.

Light fraction.—In this fraction, mica is the most abundant mineral of the Toriya sample, but it is not so plentiful in the Kami-amada fine sand, where it is subordinate to quartz and felspar. Mica, though really a "heavy" mineral, tends to float off with the light fraction on account of its flaky nature. The mica is in pale yellow flakes yielding good interference figures, and is most probably muscovite. In the Kami-amada sample the mica is more altered and most of the flakes are somewhat opaque, giving the grains a very close resemblance to the semi-opaque material usually designated as kaolinised material in other samples. Quartz is about equal in amount to felspar in the Toriya sample, but more abundant in the one from Kami-amada. It is in angular to rounded grains, clear and free from inclusions. Felspar is in pinkish angular to sub-angular plates with refractive index lower than 1.53. Some of the larger plates have cleavage lines and faint twin lamellae. Felspar is not nearly as plentiful in the Kami-amada fine sand as it is in the Toriya. Most of the grains are clear, but a few are clouded with decomposition products.

Heavy fraction.—After the removal of magnetite the heavy fractions contained over 50% of ilmenite (probably with a certain amount of magnetite which did not respond to the magnet). In both fine sands rutile was more plentiful than leucoxene, and a few crystals of anatase were found in each. A conspicuous feature is the abundance of zircon, making up over

20% of the grains traversed. The habit is varied, but most of the grains are clear and non zoned with plentiful inclusions. Broken grains are very common, but otherwise no wear or rounding is shown. The prevailing form is the elongated prism-pyramidal type, some grains being quite acicular, but others are stumpy and appear almost dodecahedral. One grain was almost tabular, the main prism being bevelled with secondary prisms. One twin was found. Some of the larger crystals are brown. A few grains of tourmaline, hornblende, epidote and (?) andalusite were also found. The plentiful zircon probably accounts for the feeble radioactivity found in these soils.

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V. SUMMARY.

The paper deals with the mineralogical description of a series of fine sand fractions of soils from South Australia, King Island (Tasmania), Western Australia, the East Indies, and Japan.

After a mineralogical description of the samples, the results are expressed in tables, frequency numbers derived from percentages being given.

The following minerals not found in soils previously described by the author (Carroll, 1931-32) were identified:—Andesine, chromite, chalcedony, dolomite, fluorite, hypersthene, kaolinite, labradorite, ? nontronite, opaline silica, ? serpentine, and ? zoisite.

CONCLUSIONS.

1. In sedentary soils the mineralogical composition of the parent rock is indicated by the mineral grains of the fine sand fraction (Wongan Hills, W.A., Kondoparinga loam, Kuitpo, S.A.). If the soil is fairly "fresh" some indication of the texture of the parent rock is given by a microscopic examination (soil from andesite, Borneo, 928b).

2. "The new-built minerals give us the best view in the chemical processes which the soil has undergone since its building." (J. van Baren, 1928.) The formation of new minerals within the soil, such as kaolinite, the clay minerals, and the titanium minerals indicate that certain chemical processes have taken place, though it is difficult to distinguish between these processes

in the weathered rock and soil. There is a gradual transition from rock to soil, and the same weathering agents act on both, though probably more intensely on the soil. (Lappa sand, King Island; soils from Borneo.)

3. In places where there are strong winds the heavier species tend to accumulate at the surface, though there is often very little difference throughout the profile. In very "fresh" soils the lower parts of the profile show more species. (Soils from Ninghan and Gabbin, W.A., show a surface enrichment of heavy fraction.)

4. An old, well-weathered soil can often be distinguished microscopically from younger soils by a smallness of grain size (within the fine sand fraction), worn appearance of grains, *e.g.* zircon, absence of merest traces of ferromagnesians, and a greater amount of decomposed, kaolinised material. This will depend, also, on the original composition and texture of the parent rocks, and on the climate in which they have been formed. The disintegration of rocks, which is the first stage in the formation of a soil, is effected more by mechanical than by chemical processes in arid climates; in more humid regions the chemical processes may predominate (Tropical soils).

5. Species of minerals foreign to a soil may arise by the addition of salts in solution from outside sources. Thus, if there is an accumulation of calcium carbonate, as in soils of the Mallee zone, calcite and dolomite are authigenously formed, and the resulting fine sand has a different appearance under the microscope. (Ninghan and Gabbin, W.A.)

6. A microscopic examination of the fine sand indicates how the colour is distributed in the soil, and to which minerals it is due (Tropical soils). The leaching of iron to lower horizons in podsols is readily shown in this way (ferruginous band in Lake Brown soil; sands from Hundred of Kuitpo, S.A.).

7. The scarcity of species and abrasion of grains serves to differentiate secondary, transported soils, or those derived from arenaceous sediments, from sedentary, primary soils (Myponga sand, S.A., sands from King Island).

8. Definite soil types can often be recognised by a microscopic examination of the fine sand grains, the type depending on the parent rock and the weathering. Several of the types described are shown in the photomicrographs.

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DESCRIPTIONS OF THE PHOTOMICROGRAPHS.

Plate IV., Figures 1 to 6.

Heavy minerals of the fine sands from the Hundred of Kuitpo, South Australia.

Figure. 1:—*Kuitpo gravelly, sandy loam.* (Sample 1848.) -Ilmenite, tourmaline, amphibole, mica, sillimanite.

Figure 2:—*Burbrook sandy loam.* (Sample 149)—Ilmenite, rutile, small zircons, and tourmaline. The elongated rounded grain near the centre is a worn rutile crystal.

Figure 3:—*Myponga sand.* (Sample 1925.)—Ilmenite, rounded tourmaline with inclusions, rounded zircon, and a little sillimanite.

Figure 4: -*Meadows sand (alluvial).* (Sample 1919.)—There are two grade sizes, the large grains somewhat similar to those of the Myponga sand and the small ones to those of the Kondoparinga loam. The large grains are ilmenite, tourmaline, sillimanite, and zircon.

Figure 5: *Meadows clay loam.* (Sample 1931.)—The photomicrograph shows the extremely small size of the grains, which are difficult to identify.

Figure 6:—*Kondoparinga loam.* (Sample 1927.)—Is similar to the Meadows clay loam, and contains practically the same minerals, *i.e.*, minute grains of ilmenite, tourmaline, zircon, and mica. The Meadows clay loam was probably derived from the Kondoparinga loam.

Two distinct types of parent material have given rise to the six types of soil described from the area.

Plate V., Figures 7 to 12.

Heavy minerals from various fine sands.

Figure 7:—*Naracoopa sand, King Island, Tasmania.* (Sample 2233.)—Ilmenite, zircon, tourmaline, and monazite, the latter more rounded than zircon and a little to the left of the centre of the mount.

Figure 8.: *Red Gum soil, Manjimup, W. Australia.* (Sample 1483.)—Ilmenite, magnetite, zircon, rutile, and kyanite, which resembles the zircon crystals, but is more elongated.

Figure 9:—*Salak, near Buitenzorg, Java.* Subsoil of recent volcanic material. (Sample 156a.)—Crystalline kaolinite (top left side of mount), (?) nontronite, ilmenite, and magnetite.

Figure 10: *Salak, near Buitenzorg, Java.* Soil from recent volcanic material. (Sample 156d.) Ilmenite, magnetite, hypersthene (prismatic grain in lower part of mount), (?) nontronite, and euhedral quartz (just above the hypersthene).

Figure 11: *Ninghan, Avon Location 579, W. Australia.* (Sample 1634.)—Ilmenite, zircon, rutile, amphibole, and dolomite (near edge N.E. in mount).

Figure 12:—*Kami-amada, Ishikawa prefecture, Japan.* -Ilmenite, zircon, and amphibole (just east of centre).

TABLE 2.

MINERALOGY OF THE FINE SANDS.

Locality	Manjimup, W.A.								Java							
Description	Karri Soil.								Recent Volcanic.				Volcanic.		Limestone.	
Sample No.	1473	1474	1475	1476	1477	1478	1479	1480	156d	156c	156b	156a	993b	993a	1000c	1000b
Depth of sample	0″ to 9″	9″ to 18″	0″ to 9″	9″ to 18″	0″ to 9″	9″ to 18″	0″ to 9″	9″ to 18″	8″ to 1 M	2nd layer	3rd layer	4th layer	0″ to 30cm.	30cm.	0″ to 15cm.	15″ to 105cm.
Heavy Fraction—																
Ilmenite	8+	8+	8+	8+	8+	8+	8+	8–	7–	8–	8–	7+	8	8+	8	8–
Leucoxene	1*	1	2	1	1	1*	2	1	1	4	1	1	1	1	2	1
Rutile	1*	1*	...	1*	1*	1*	1*	1*	1*	...	...	1	1*	1*	1*	2
Anatase	...	...	...	...	...	...	...	...	...	...	...	...	...	1*	1	...
Magnetite	...	...	...	...	...	...	...	...	A	A	a	A	s	s	a	a
Limonite	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...
Hematite	...	...	...	...	...	...	...	...	...	2	1	4	...	...	...	...
Chromite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Pyrite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Amphibole	...	...	...	...	...	...	...	...	...	...	1*	...	1*	1*	2	1*
Pyroxene	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Hypersthene	...	...	...	...	...	...	...	...	6	...	...	...	5	1*	4	1
Epidote	...	...	...	...	...	...	1*	1*	...	...	...	...	...	...	...	...
Muscovite	...	...	...	...	...	...	...	...	1	1*	...	...	...	...	...	...
Biotite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Nontronite	...	...	...	...	...	...	...	...	5	6+	7–	7	1*	2	2	7–
Andalusite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Fluorite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Garnet	...	...	...	...	...	...	1*	...	...	...	...	...	...	...	...	...
Kyanite	1*	1*	...	...	...	...	1*	1*	...	...	...	...	...	...	2	...
Sillimanite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1*
Tourmaline	...	...	...	...	1*	...	1*	1*	...	1*	...	...	...	1	2	2
Zircon	4	4	3	4	2	2	4	5	2	2	2	1*	2	2	4	2
? Zoisite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Dolomite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Kaolinite	...	...	...	...	...	...	...	...	...	...	2	3	...	1*	...	...
Chalcedony	...	...	...	...	...	...	...	...	2	1	3	4	2	4	...	...
Opaline SiO_2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Light Fraction—																
Quartz	8+	8+	8	8	8	8	8–	8––	5	5	5	5	5	5	6	6
Felspar	...	? P	2	P	4	4	...	...	...	...	...	...	...	...	? P	? P
Andesine	...	...	...	...	...	...	...	...	...	...	...	...	6	6	...	...
Labradorite	...	...	...	...	...	...	...	...	5	5	5	5	6	6	...	...
Oligoclase	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Microcline	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Microperthite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Nontronite	...	...	...	...	1	P	...	P	P	P	P	P	P	P	...	...
Kaolinite	...	...	...	...	...	...	...	...	4	5	6–	6	...	...	...	...
Kaolinised mat.	...	...	...	...	P	...	...	...	8	8–	8–	8–	7+	7+	...	...
Mica	...	...	...	...	...	...	...	...	...	...	...	...	3	3	...	...
Ferruginous mat.	5	5	6	6–	6–	6–	5	6	...	...	...	...	...	...	8	8
Orthoclase	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plagioclase	...	...	...	4	...	...	7–	6+	...	...	...	...	...	...	...	...
Chalcedony	...	...	...	...	...	...	...	...	P	P	1	1	1	2	2	2
? Chlorite	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
? Serpentine	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Opaline SiO_2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Locality	Borneo				Western Australia. Ninghan.					
Description	Gabbro.		Pd.	An.	Mallee Soil.					
Sample No.	930b	1135b	924c	928b	1634	1635	1636	1637	1638	1639
Depth of sample	S	S	S	S	0″ to 3″	3″ to 12″	12″ to 27″	27″ to 46″	46″ to 72″	72″ to 75″
Heavy Fraction—										
Ilmenite	7+	8	8	8–	7	7+	8–	7+	7+	8–
Leucoxene	2	3	5	6+	4	4	4	5	4	5
Rutile	1	...	1	1*	2	3	1*	1	2	1
Anatase	...	...	...	...	...	...	...	...	...	...
Magnetite	...	A	a	A	...	...	...	...	...	...
Limonite	6 –	6 –	3	1	...	...	...	...	...	...
Hematite	...	...	...	...	...	...	...	...	...	...
Chromite	...	...	a	...	...	...	...	...	...	...
? Pyrite	...	...	...	...	...	...	...	...	...	...
Amphibole	1	...	...	P	1	2	2	2	1	2
Pyroxene	...	3	...	5	...	...	...	...	...	...
Hypersthene	...	...	...	...	...	...	...	...	...	...
Epidote	6	...	P	2	2	...	...	1*	1*	1*
Muscovite	...	...	...	...	...	...	...	1*	...	...
Biotite	...	...	...	...	...	...	...	...	...	1*
? Nontronite	...	...	...	...	...	1	2	P	...	...
Andalusite	...	...	...	...	...	...	...	...	...	...
? Fluorite	...	...	...	...	...	...	...	...	...	...
Garnet	...	1*	...	1*	...	...	1*	1*	...	...
Kyanite	...	...	...	...	...	...	...	...	...	...
Sillimanite	...	...	...	...	...	...	...	...	1*	...
Tourmaline	1	...	...	...	1*	...	...	1*	1*	1
Zircon	1*	...	4	2	7	7–	7–	7–	7	7–
? Zoisite	...	...	...	...	...	...	...	...	...	...
Dolomite	...	...	...	...	5	...	...	...	...	...
Kaolinite	...	...	...	...	...	...	...	...	...	...
Chalcedony	...	...	...	...	...	...	...	...	...	...
Opaline SiO_2	...	...	...	...	...	...	...	...	...	...
Light Fraction—										
Quartz	...	...	...	...	6–	6	6+	6+	7	7+
Felspar	...	? P	...	...	...	...	...	...	...	...
Andesine	...	...	...	...	...	...	...	...	...	...
Labradorite	8+	...	8+	8+	...	...	...	...	...	...
Oligoclase	...	...	...	...	...	...	...	...	...	...
Microcline	...	...	...	...	...	...	...	...	...	...
Microperthite	...	...	...	...	...	P	P	...	...	...
? Nontronite	...	...	...	...	8–	8–	7+	7–	7–	6–
Kaolinite	...	...	...	...	...	...	...	...	...	...
Kaolinised mat.	5	? P	P	...	5	P	P	P	P	P
Mica	...	5	...	...	...	...	...	...	...	...
Ferruginous mat.	...	8–	...	P	P	P	P	P	P	...
Orthoclase	...	...	...	...	4	6–	6–	6–	6	6–
Plagioclase	...	...	...	...	...	4	5	5	5	6
Chalcedony	...	...	...	...	...	...	...	...	...	...
? Chlorite	...	2	...	5	...	...	...	...	...	...
? Serpentine	...	...	5	...	...	...	...	...	...	...
Opaline SiO_2	...	...	...	...	...	P	P	P	...	...

Locality	Western Australia. South Gabbin.					Western Australia. Wongan Hills.			Japan
Description	Mallee Soil.					? Lateritic.			? Late
Sample No.	1640	1641	1642	1643	1644	5007	5008	5009	K.A.
Depth of sample	0″ to 2″	2″ to 6″	6″ to 12″	12″ to 24″	24″ to 36″	0″ to 8″	8″ to 18″	18″ +	S
Heavy Fraction—									
Ilmenite	7+	8–	8–	8–	8–	7+	7+	7–	7–
Leucoxene	2	4	3	4	4	5	4	4	3
Rutile	2	1*	1	2	2	1	2	3	5
Anatase	...	...	...	...	...	1*	1*	1	1*
Magnetite	...	...	...	...	...	...	...	...	...
Limonite	...	...	...	...	...	...	...	...	...
Hematite	...	...	...	...	...	...	...	...	2
Chromite	...	...	...	...	...	...	...	...	...
? Pyrite	...	...	1*	...	...	...	...	...	...
Amphibole	3	2	3	...	2	1*	...	P	2
Pyroxene	...	...	...	...	...	...	1*	...	...
Hypersthene	...	...	...	...	...	...	...	...	...
Epidote	1*	1*	1*	...	...	4	4	2	3
Muscovite	...	...	...	...	...	...	...	1	A
Biotite	...	...	...	...	...	...	...	...	...
? Nontronite	1	...	...	2	3	6–	5	5	...
Andalusite	...	...	...	...	...	...	...	3	...
? Fluorite	...	1*	...	...	...	...	...	...	...
Garnet	...	...	...	1*	...	...	1*	1*	...
Kyanite	1*	...	...	...	...	...	...	1*	...
Sillimanite	1	1	...	...	...	1	...	1*	...
Tourmaline	2	1	1	...	...	1	1	1	...
Zircon	7–	6+	7–	6	6+	6–	6+	6	7–
? Zoisite	1	...	...	...	...	...	...	...	...
Dolomite	5	5	...	...	...	...	...	...	...
Kaolinite	...	...	...	...	...	...	...	...	...
Chalcedony	...	...	...	3	...	...	...	...	...
Opaline SiO_2	1*	...	...	...	...	...	...	...	...
Light Fraction—									
Quartz	7	7	7	7	7	7+	7+	8–	7
Felspar	...	...	...	...	...	...	...	...	...
Andesine	...	...	...	...	...	...	...	...	...
Labradorite	...	...	...	...	...	...	...	...	...
Oligoclase	...	...	...	P	P	...	...	...	...
Microcline	...	P	...	...	...	...	...	...	...
Microperthite	...	...	...	...	...	...	...	...	...
? Nontronite	7	7	7	7	7	...	...	...	...
Kaolinite	...	...	...	...	...	...	...	...	...
Kaolinised mat.	P	P	P	P	P	2	4	4	P
Mica	...	...	...	...	...	...	...	...	7–
Ferruginous mat.	...	...	...	...	...	...	P	P	...
Orthoclase	6–	6–	6–	6	6	7	7	7–	6–
Plagioclase	5	5	5	5	5	5	4	4	...
Chalcedony	...	...	...	...	...	...	...	...	...
? Chlorite	...	...	...	...	...	...	...	...	...
? Serpentine	...	...	...	...	...	...	...	...	...
Opaline SiO_2	...	...	...	...	...	...	...	...	...

Pd = Peridotite.
An = Andesite.
S = Surface.

P = Present.
A = Abundant.
a = fairly plentiful.

s = Scarce.
Ka = Kami-amada.
T = Toriya.

An.	Western Australia.														Jap
	Ninghan.						South Gabbin.					Wongan Hills.			
	Mallee Soil.						Mallee Soil.					? Lateritic.			? Late
28b	1634	1635	1636	1637	1638	1639	1640	1641	1642	1643	1644	5007	5008	5009	K.A.
S	0″ to 3″	3″ to 12″	12″ to 27″	27″ to 46″	46″ to 72″	72″ to 75″	0″ to 2″	2″ to 6″	6″ to 12″	12″ to 24″	24″ to 36″	0″ to 8″	8″ to 18″	18″ +	S
8−	7	7+	8−	7+	7+	8−	7+	8−	8−	8−	8−	7+	7+	7+	7+
6+	4	4	4	5	4	5	2	4	3	4	4	5	4	4	3
1*	2	3	1*	1	2	1	2	1*	1	2	2	1	2	3	5
...	...	...	...	...	...	...	...	...	...	...	...	1*	1*	1	1*
A	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	1*	...	...	...	...	...	...
P	1	2	2	2	1	2	3	2	3	...	2	1*	...	P	2
5	...	...	...	...	...	...	...	...	...	...	...	...	1*	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2	2	...	...	1*	1*	1*	1*	1*	1*	...	...	4	4	2	3
...	...	...	...	1*	...	...	...	...	...	...	...	...	...	1	A
...	...	...	...	...	...	1*	...	...	...	...	...	...	...	...	...
...	...	1	2	P	...	...	1	...	...	2	3	6−	5	5	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	...
...	...	...	...	...	...	...	...	1*	...	...	...	...	...	...	...
1*	...	...	1*	1*	...	...	...	...	...	1*	...	...	1*	1*	...
...	...	...	...	...	...	...	1*	...	...	...	...	...	...	1*	...
...	...	...	...	...	1*	...	1	1	...	...	...	1	...	1*	...
..	1*	...	...	1*	1*	1	2	1	1	...	...	1	1	1	...
2	7	7−	7−	7−	7	7−	7−	6+	7−	6	6+	6−	6+	6	7−
..	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...
...	5	...	...	...	...	...	5	5	...	...	...	...	...	...	...
..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
..	...	...	...	...	...	...	...	...	...	3	...	...	...	...	...
..	...	...	...	...	...	...	1*	...	...	...	...	...	...	...	...
..	6−	6	6+	6+	7	7+	7	7	7	7	7	7+	7+	8−	7
..	...	...	...	..	...	...	...	...	...	...	...	...	...	...	...
..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8+	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
..	...	...	...	...	...	...	...	...	...	P	P	...	...	...	...
..	..	...	...	...	...	...	...	P	...	...	...	...	...	...	...
..	...	P	P	...	...	...	...	...	...	...	...	...	...	...	...
..	8−	8−	7+	7+	7−	6−	7	7	7	7	7	...	...	...	...
..	5	P	P	P	P	P	P	P	P	P	P	2	4	4	P
P	P	P	P	P	P	...	...	...	...	...	...	...	P	P	7+
..	4	6−	6−	6	6	6−	6−	6−	6−	6	6	7	7	7 −	6 −
..	...	4	5	5	5	6	5	5	5	5	5	5	4	4	...
..	...	...	..	...	...	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
.	..	...	..	...	...	...	...	...	...	...	...	...	...	...	...
..	...	P	P	P	...	...	...	...	...	...	...	...	...	...	..

Scarce.
Kami-amada.
Toriya.

PLATE IV.

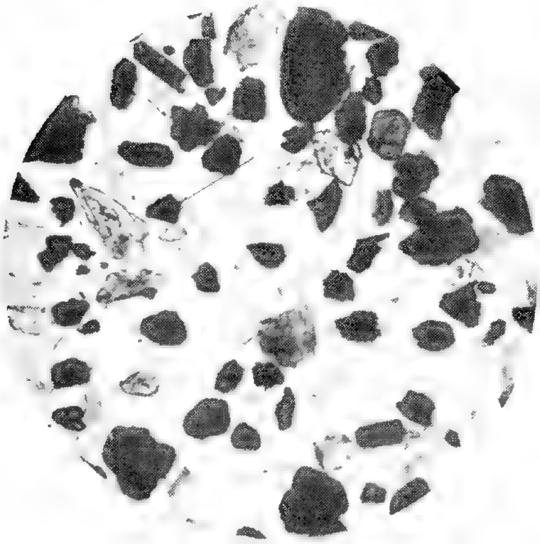

Fig. 1. × 40.

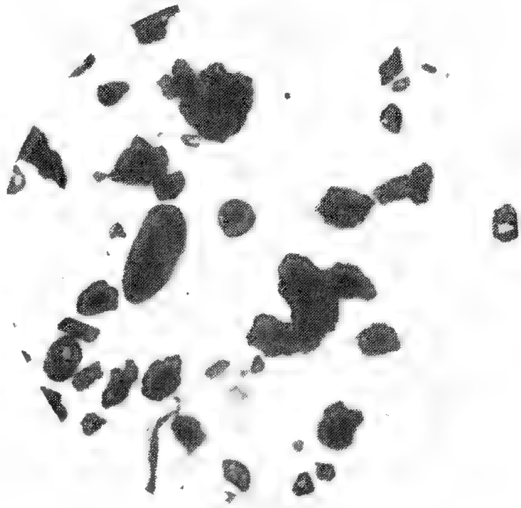

Fig. 2. × 40.

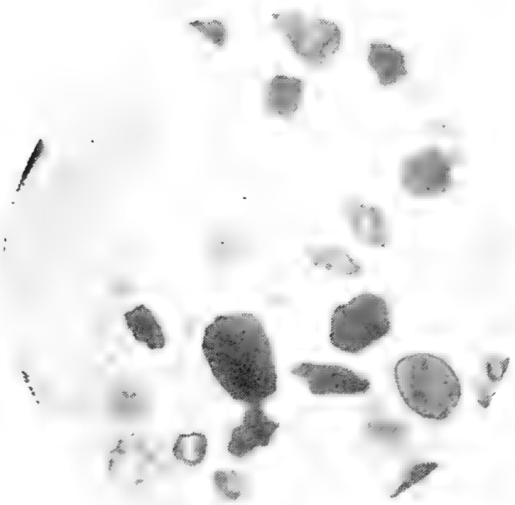

Fig. 3. × 47.

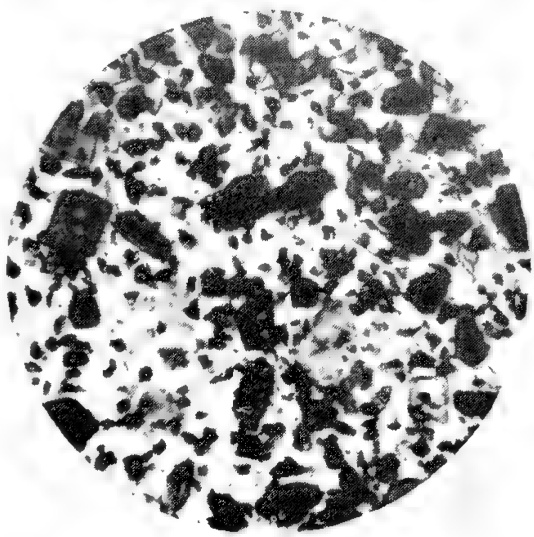

Fig. 4. × 38.

Fig. 5. × 40.

Fig. 6. × 40.

[*Photo., H. J. Smith.*]

PLATE V.

Fig. 7. × 40.

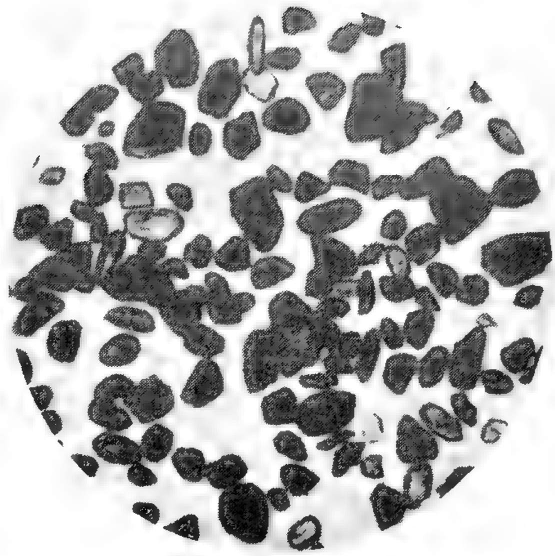

Fig. 8. × 40

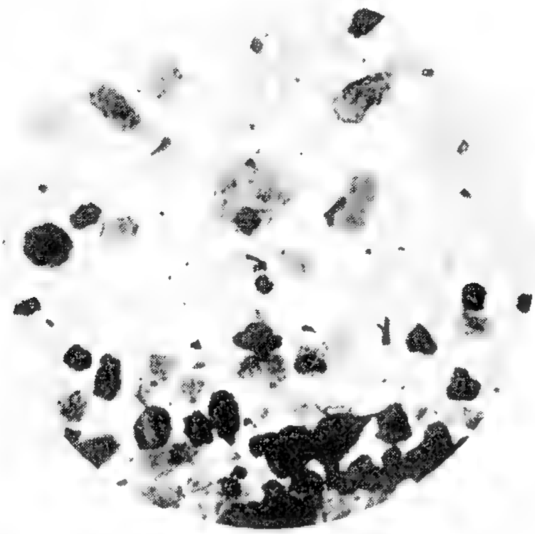

Fig. 9. × 34.

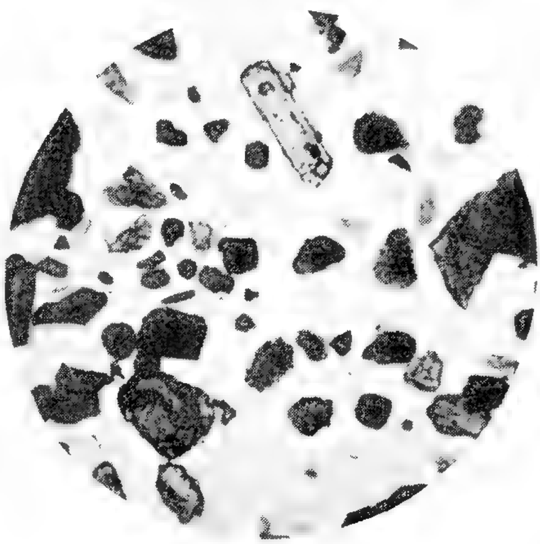

Fig. 10. × 38.

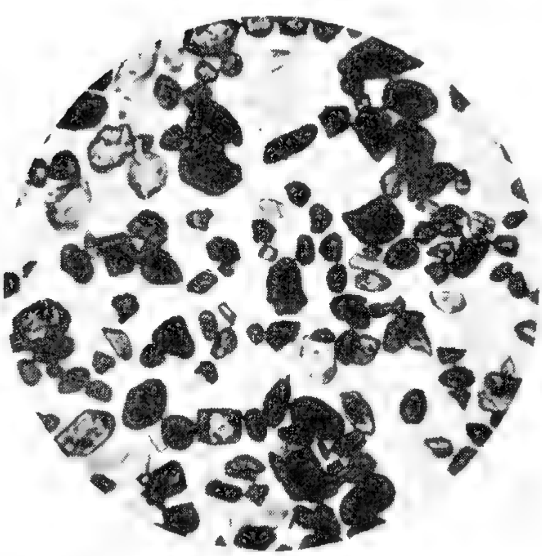

Fig. 11. × 47.

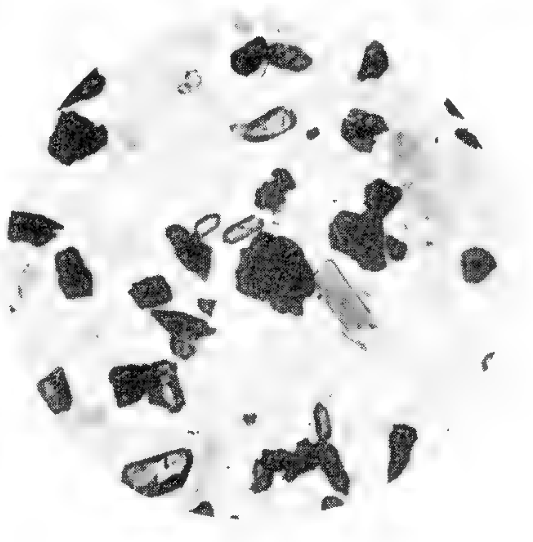

Fig. 12. × 40.

[*Photo., H. J. Smith.*]

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

6.—THE PALAEONTOLOGY OF THE PLANTAGENET BEDS OF WESTERN AUSTRALIA.

BY FREDERICK CHAPMAN, A.L.S., Hon. F.R.M.S., F.G.S.
AND
IRENE CRESPIN, B.A.

Read 8th May, 1934. *Published 3rd October,* 1934.

Communicated by L. Glauert.

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I.—INTRODUCTION.

In 1917 Messrs. J. T. Jutson, B.Sc., LLB., and E. S. Simpson, B.E., D.Sc., F.A.C.I., favoured us with a large collection of Cainiozoic fossils, including those which they had obtained from Albany, and those which members and correspondents of the Geological Survey had obtained from Cape Riche and Norseman, Western Australia. This fossiliferous series they had already named as "The Plantagenet Beds." (Jutson and Simpson, 1915, p. 48.)

The collection as it is now described in detail comprises all the abovementioned specimens, and we are further indebted to the Curator of the Western Australian Museum, Mr. L. Glauert, B.A., F.G.S., for a further collection of fossils, chiefly mollusca, and to Mr. T. Blatchford, B.A., late Government Geologist of Western Australia, for a very extensive collection of fossil sponges he had collected in the Hamersley River District.

A few years ago a paper on the Jutson and Simpson collections was published under the title of some "Preliminary Notes on the Fauna and Age of the Plantagenet Beds of Western Australia," by the present authors, and was issued in the Report of the Australasian Association for the Advancement of Science for 1924 (Chapman and Crespin, 1926, pp. 319–322). This paper has an epitomy of the results of an examination of the Jutson and Simpson collections. The present paper represents a detailed study of the earlier collection referred to, with the addition of a description of the Glauert collection.

Since the preliminary paper above referred to was published, L. Glauert has given a supplementary list of Western Australian Fossils (Glauert, 1926, pp. 62, 63), in which he included the names of some mollusca from these beds, which, although not precisely stated, appear to be Glauert's own determination of some specimens in the collection of the Western Australian

Museum. These were apparently provisional, and in certain cases appear to differ from similar forms which Miss Crespin and I have recorded in the preliminary paper. Mr. Glauert kindly forwarded the above collection, together with a supplementary one of fossil sponges from the Geological Survey of Western Australia to the National Museum, Melbourne, for our examination, and this was received on the 12th October, 1927. These series, including the types, will be returned to the Western Australian Museum and Art Gallery, and Geological Survey, at the conclusion of the work.

In a paper published in 1924 on the Geology of the Mineral Industry in Western Australia, by A. Gibb Maitland and A. Montgomery (Maitland and Montgomery, 1924), there are references to the Western Australian Tertiary rocks on pages 41 to 45, and on page 41, fig. 16, is a striking photograph of the type of stratification seen in the limestone cliffs at Twilight Cove, Eyre.

For detailed references to papers relating to the occurrence of fossils belonging to the Plantagenet Series, down to 1919, the reader is referred to "Preliminary Notes on the Fauna and Flora of the Plantagenet Beds of Western Australia" (Chapman and Crespin, 1926, pp. 319, 320).

Some years ago one of us gave a list of Miocene fossils from the Ooldea District in the western part of South Australia (Chapman, 1920, pp. 243 and 244), which comprises a large percentage of mollusca common to that area and the Plantagenet beds of Western Australia. L. Glauert (1926, pp. 61–63) has also listed the Cainozoic fossils of Western Australia, comprising Hinde's determinations of the "Princess Royal" sponge-remains, J. W. Gregory's polyzoa, and his own records of mollusca, etc. from the Plantagenet beds. In this list, the series of foraminifera from the Cape Range is omitted, as also the names of the fossils from the Albany and Cape Riche beds collected by Jutson and Simpson (Chapman and Crespin, 1926), which latter paper, however, was possibly not published before this list of the same year. As already indicated, the fossils referred to in Glauert's list of 1926, have been kindly loaned by Mr. Glauert through the National Museum.

II.—THE ALBANY, CAPE RICHE, AND NORSEMAN BEDS—STRATIGRAPHICAL AND LITHOLOGICAL NOTES.

The variably constituted sediments which Messrs. J. T. Jutson and E. S. Simpson have named the Plantagenet Series (Jutson and Simpson, 1917, p. 48), and "believe - - - will ultimately be determined as of Miocene age," have since been conclusively proved to belong to that period (Chapman and Crespin, 1926, p. 321). Jutson and Simpson wrote their statement as to probable age in 1915, but their paper was not published until 1917; meanwhile J. W. Gregory had published a note in the Geological Magazine in 1916, giving the evidence of mollusca determined by A. E. Kitson, and of polyzoa by himself (Gregory, 1916, pp. 320–321). Professor Gregory stated that "their evidence is in favour of the Miocene rather than of the Pleistocene age of the Norseman Limestone" (*loc. cit.*, p. 321).

The sediments comprised in the Plantagenet Series were laid down in hollows on a granite platform. This granite has been intersected in places by basic dykes (dolerite and basalt), ranging in width from less than an inch to many yards. One dyke (a supposedly later intrusion) cuts through granite and Miocene sediment alike (Jutson and Simpson, 1917, p. 48).

The variation in the types of Miocene sediments represented in the present collection is considerable, and from each locality the fossiliferous specimens will be examined in detail. Overlying the Plantagenet beds, especially

nearer the Coast is an accumulation of dune limestone, which Jutson and Simpson have named the Darwin Ridge in honour of Darwin, who made observations here, at Bald Head during the voyage of the "Beagle." Probably the age of these consolidated dunes is similar to that of the dunes at Sorrento, Warrnambool, and other localities along the Victorian Coast. In the present case, as Jutson and Simpson remark, "they were formed subsequent to the deposition and uplift of the Plantagenet Marine beds."

These Pleistocene deposits may be closely compared with those of the Ooldea region, near the western border of South Australia, where I have recorded (Chapman, 1920, p. 245) an uplift of 381 feet, and extending as far inland as 100 miles. This was referred to in the paper mentioned as Older Pleistocene, since it was overlain in places by the raised beach formations during sub-recent movements.

THE ALBANY AND CAPE RICHE SEDIMENTS.

This series is typically exposed in a brick-pit three miles north-west of Albany. The beds have been laid down on an irregular granitic surface and retain their original horizontal position, notwithstanding subsequent elevation and depression. "The Plantagenet beds near Albany rise to a height of 170 to 220 feet or more above sea-level, but their maximum thickness is not known" (Jutson and Simpson, 1917, p. 52).

These sediments consist of fine-grained siliceous rocks, varying from white to pale pink and yellowish brown. The Albany siliceous rock is moderately friable, whilst that from Cape Riche is much more tenacious. The material appears to be largely derived from the detritus of siliceous sponge spicules, and there are numerous casts and moulds of fossils shown on fractured surfaces. Wax or plasticene squeezes from these often yield good results in the determination of genera, and even species of mollusca and echinoids. Faithful impressions of leaves have been formed in the more solid siliceous rock of Cape Riche. Messrs. Jutson and Simpson (1917, pp. 48, 49) remark about the Albany rock that "Siliceous sponges are especially abundant throughout these beds, many complete skeletons of lithistids being obtainable, whilst isolated spicules of the same and of tetractinellids form an important proportion of the whole rock." In addition, those authors note, the uniformly fine grain of the rock, the small proportion of kaolin, almost total absence of calcium or magnesium carbonates, the larger proportion of purely siliceous material present (83·62% in the white stone of Cape Riche, and 82·58% in the yellow).

A microscopic examination of the powdery residue washed from the Albany siliceous rock shows numerous broken sponge spicules, minute irregular quartz grains, a fair proportion of foraminiferal casts (*Spiroplectammina* and *Discorbis*), together with about 50% of a fine siliceous silt.

The siliceous rocks from Cape Riche that we have examined are largely composed of sponge spicules, generally broken and worn into a fine mud, but in some cases the rock is of a clean spicular type. As a rule the spicules are best seen in the whitish rock, whilst that with the yellow sandy matrix carries the impressions of leaves, and moulds and casts of molluscan shells.

NORSEMAN.

This locality is represented by hard, siliceous, or jasperised shelly, and polyzoal limestones. These were collected by Dr. E. S. Simpson. In parts the rock is ochreous, or otherwise ferruginous, and of a yellow to reddish

brown colour. It appears to be without a trace of calcareous matter. The polyzoa and mollusca are conspicuous on the weathered surfaces of the slabs, but are not very well preserved, so that determination is difficult. This deposit was probably laid down in moderately deep water.

The sponge spicule deposit of the Princess Royal Deep Lead, Lake Cowan, Norseman District, was described by Dr. Hinde (Hinde, 1910), to whom it was sent by A. Gibb Maitland, then Director of the Geological Survey of Western Australia, a few months before that date. From available details of the occurrence of this spicule bed one is justified in doubting that this is a true Deep Lead, for the adjoining surface is a kaolinized deposit, "probably mostly decomposed rock in situ" (Hinde, 1910, p. 7), with the spicule deposit evidently lying upon it as a remanie layer related to the sponge bed elsewhere found at Albany.

The rock examined by Dr. Hinde, which yielded such a large variety of sponge remains, is of quite a different nature to the samples submitted to us by Messrs. Jutson and Simpson, as above-mentioned. The deposit described by Hinde (1910, p. 8) consisted "of a very light, whitish, finely granular, and powdery material, which is so incoherent, tender, and friable that it readily breaks up into dusty powder between the fingers, and when treated in water with a soft brush it passes into a greyish mud. It may be said to be an aggregation of fine particles without any cementing material to bind them together. There is no indication of bedding to be seen in the lumps. Treated with dilute hydrochloric acid, the rock shows no reaction whatever."

Dr. Hinde found the rock, under a lens, to be "composed" of minute glassy rods and granules, and occasionally of entire sponge spicules. He also notes "some minute grains of a dark mineral, and also more numerous clear granules, mostly of quartz." The only organic remains that Dr. Hinde found in this rock belonged to the siliceous sponges, and his identifications are included in our complete list of fossils at the end of Section III.

The only material we have seen resembling that described by Hinde from the Norseman (?) Deep Lead in the other collections, is a small sample included in the Albany Series, sent by Dr. Simpson.

Another phase of rocks in the Norseman district occurs as patches of limestone found on the surface of the Dundas Goldfield at an altitude of 900 feet above sea level, and 100 miles from the coast. These limestones, of which our present samples appear to be a silicified modification, were described by Professor J. W. Gregory (1916, p. 320), who gave some determinations of the included fossil polyzoa and a short list of the mollusca identified by A. E. (now Sir Albert) Kitson. These are also included in our list at the end of Section III.

The geological occurrence of the Norseman beds has been dealt with by A. Gibb Maitland (1908, p. 153) and by W. D. Campbell (1906, p. 22).

LOCALITIES AND OCCURRENCE OF TERTIARY FOSSILS LOANED FROM THE MUSEUM AND ART GALLERY, PERTH, AND FROM THE W. A. GEOLOGICAL SURVEY, 12TH OCTOBER, 1927.

List furnished by L. Glauert, F.G.S. Notes by present authors.

Albany District. *Nos.* 6041–6043.
(Shell casts in whitish siliceous rock).

Near Cheyne Beach. *Nos.* 6039, 6040
(Fossil casts in whitish siliceous rock).

Brick Works, 3 miles N.E. Albany. Nos. $\frac{1}{4131}$ (1–5).
(Casts of fossils in whitish siliceous rock).

Hassell's Homestead. Nos. $\frac{1}{4136}$ (1–3).
(Hard yellowish siliceous rock with casts and moulds of molluscan shells).

Hassell's Road, 10 *miles Cheyne Beach. Nos.* 5435–6.
(Yellowish spongy siliceous rocks with shell impressions.)

King River, Near Albany. Nos. 6044–6.
(Fossil casts and impressions in ironstone).

Warriup Homestead. Nos. $\frac{1}{4133}$ (1–4).
(Casts of mollusca in silicified limestone).

Sugar Bag Creek, Albany. Nos. $\frac{1}{4132}$ (2, and 5–9).
(Fossil impressions and casts in spicular chert. Similar to Warriup Homestead).

Hill, 1 *mile from Warriup Homestead. Nos.* $\frac{1}{4134}$ (3).
(A siliceous sponge replaced by ironstone).

Bremer Bay. Nos. G3726 and 6049–54.
(Casts of fossils in pink to brown limestone).

Hamersley River District, East of Albany.

Nos. $\frac{1}{H27}$, $\frac{1}{3903}$, $\frac{1}{3964–7}$, $\frac{1}{3969–71}$, $\frac{1}{3977–82}$, $\frac{1}{3984–94}$.

(A rich sponge bed, of siliceous forms, in which the entire sponge-body is often extremely well preserved. At times the sponges have their siliceous character almost replaced by limonite, and thus pass into a ferruginous earth).

Cape Riche. Nos. 277–279, 309, 314, 405, 5718.
(Casts and impressions of leaves, shells and echinoids, in a whitish fawn-coloured siliceous rock).

Balladonia, Eucla District. Nos. 3247–63.
(Fossils, chiefly as casts and moulds, in pale reddish limestone, of Miocene age. Also hard grey limestone of Upper Miocene or Pliocene age, containing *Marginopora vertebralis*).

Little Bluff. Nos. $\frac{1}{4135}$ (1–2).
(Yellowish spicular rock).

III.—DESCRIPTION OF NEW AND RARE SPECIES.

PLANTAE.

Series CONIFERALES.

Genus AGATHIS Salisbury, 1807.

(*Dammara* Lamb: 1786, is a genus excluded from the Australian flora).

Agathis cf *Intermedia* (Ettingshausen).

Dammara intermedia, Ettingshausen, 1888, p. 98, pl. VIII, figs. 34–38. Deane, 1925, p. 495, pl. LXI, fig. 5; pl. LXIII, figs. 12, 15.

Observations.—A leaf-fragment, referable to the above genus of conifers, occurs on a slab of fine siliceous mudstone, associated with *Bombax.* and

1. The affinities of leaves of Australian examples referred to this genus have been questioned by the late Henry Deane, F.L.S., in conversation with the present writer. Deane was inclined to ascribe such foliage to *Kennedya* or an allied genus.

marine shells. The shape of the fragment indicates a long-ovate type with distinct parallel venation and measures 30mm. in length. The completed lamina might measure 10mm. across. This may be compared with *D. intermedia*, a species that Henry Deane identified in the Miocene leaf-bearing seams of the Brown Coal deposits at Yallourn, near Morwell, Victoria.

Occurrence.—Cape Riche, Albany district, W. Australia (Simpson collection).

Nat. Order FAGACEAE.

Genus NOTHOFAGUS Blume 1850.

Nothofagus Wilkinsoni (Ettingshausen).

Fagus Wilkinsoni Ettingshausen, 1888, p. 32, pl. II, fig. 1, 1A.

Observations. Ettingshausen has noted that of the three Australian species of *Nothofagus*, ("*Fagus*") *N. Moorei* approaches most nearly to the above fossil species, both in the form and simple dentation, with secondary veins ending at denticles. The length of the incomplete lamina is 34mm., but when entire probably measured about 85mm. It has a width of 40mm., and with an average space between the secondary veins of 6mm. It agrees with Ettingshausen's figures. Associated with this leaf is a mould of the estuarine gasteropod genus *Potamides*. belonging to a species named in MS. by the late John Dennant, and now in the Dennant Collection at the National Museum. We now describe this (see *infra*) under Dennant's cheironym of "*Potamides nullarboricum.*" From its previous occurrence at Aldinga Bay and the Nullarbor Plains it helps to fix the age of the Cape Riche beds.

Occurrence.—In the fine siliceous mudstones of Cape Riche (Simpson collection).

Nat. Order MALVACEAE.

Genus BOMBAX Linné, 1753 (L.).

Bombax Sturtii Ettingshausen, Pl. VI., fig. 1.

Bombax Sturtii Ettingshausen, 1888, p. 60, pl. VI, fig. 1. Tate and Watt, 1896, p. 67.

Observations.—A fine and nearly complete example of this form of leaf found associated with marine shell impressions on the same slab, is comparable with Ettingshausen's fig. 1. The lanceolate shape with ovately curving sides, the strong midrib and the gently and evenly curving secondary ribs at about 35° to the former, confirms this determination. *B. Sturtii* has been previously recorded from Dalton, near Gunning, N.S. Wales, and from Elizabeth River, West of Lakes Eyre and Torrens, S. Australia.

Occurrence.—Cape Riche. (Simpson collection).

Bombax Mitchelli Ettingshausen.

Bombax Mitchelli Ettingshausen, 1888, p. 61, pl. VI., fig. 2

Observations.—The present specimen represents a broader type of leaf than that of the foregoing species, and it has the secondary veins emerging from the midrib at a wider angle. More than half the leaf is preserved, as an impression, which can be closely compared with Ettingshausen's fig. 2 (*loc. cit.*), which came from Dalton, N.S. Wales.

Occurrence.—Cape Riche. (Glauert Collection, No. 277.).

ANIMALA.

PHYLUM PROTOZOA.

Order FORAMINIFERIA.

Family PENEROPLIDAE.

Genus MARGINOPORA Quoy & Gaimard.

Marginopora vertebralis, Q. & G.

Observations.—The examples from the Balladonia limestone occur in a hard grey limestone which is evidently a slightly different phase from the ordinary pink limestone of the same collection. It seems that there is no doubt that it belongs to the same age as the other specimen for it has already been recorded from limestones as old as this from the Ooldea District, South Australia (Chapman, 1920. P. 232). Although this is an exceptionally large specimen measuring 1 inch in diameter, it is eclipsed by that from Ooldea which reached 1½ inches.

Occurrence.—Balladonia limestone. Eucla District. (No. 3263).

Phylum PARAZOA (Spongiae).

Class **SILICISPONGIAE**.

Order MONACTINELLIDA.

Family TETHYIDAE.

Genus TETHYA Lamarck.

Tethya aff. *Robusta* Bowerbank.

Hinde, 1910, p. 15, pl. 11, fig. 18.

Observations.—Globostellate spicules from Norseman resembled those from the above species, still living in Australian seas.

Occurrence.—Norseman (G. J. Hinde).

Fam. SPIRASTRELLIDAE.

Genus LATRUNCULIA Bocage

Latrunculia sp.

Hinde, 1910, p. 11, 12. pl. 1. fig. 17, 18, 20, 21.

Observations.—Hinde records *Sceptrella* or chessmen flesh spicules, referable to this genus.

Occurrence.—Norseman (G. J. Hinde).

Fam. HAPLOSCLERIDAE.

Genus HALICHONDRIA Fleming.

Halichondria sp.

Hinde, 1910, p. 10, pl. 1. f. 7.

Observations.—Hinde compares acerate spicules from Norseman with similar forms from Oamaru, New Zealand, and also with the recent *Halichrondria infrequens*, Carter, from the Gulf of Manaar.

Occurrence.—Norseman (G. J. Hinde).

Genus PETROSIA Vosmaer.

Petrosia cf. *Variabilis* Ridley.

Hinde, 1910, p. 10, pl. 1, f. 3.

Observations.—Fusiform acerate spicules, recorded by Hinde.

Occurrence.—Norseman (G. J. Hinde).

Fam. DESMACIDONIDAE.

Genus DESMACIDON Bowerbank

Desmacidon (*Homoeodictya*) *gradnis* Ridley and Dendy.

Hinde, 1910, p. 10. pl. 1. f. 2.

Observations.—Fusiform acerate spicules compared by Hinde with those of the living sponge from Simon's Bay, Cape of Good Hope.

Occurrence. Norseman (G. J. Hinde).

Genus FORCEPIA Carter.

Forcepia cf. *Crassanchorata* Carter.

Hinde, 1910, p. 11. pl. 1. f. 15.

Observations.—Spicules compared by Hinde to the living *F. crassanchorata* from Pt. Elliot, South Australia.

Occurrence. Norseman (G. J. Hinde).

Fam. HAPLOSCLERIDAE.

Genus STRONGYLOPHORA Dendy

Strongylophora, sp.

Hinde, 1910, p. 11, pl. 1. f. 8, 9.

Observations.—The Norseman material described by Dr. Hinde contains, according to that author, "slightly curved cylindrical spicules, smooth, with ends evenly rounded." He compares the spicules with those seen in *Strongylophora durissima* Dendy, from the Gulf of Manaar.

Occurrence.—Norseman (G. J. Hinde).

Order TETRACTINELLIDA.

Fam. TETILLIDAE.

Genus CRANIELLA O. Schmidt.

Craniella, sp.

Hinde, 1910, p. 14. pl. 11. f. 3.

Observations.—Trifid spicules with simple head-rays directed upwards, were found by Hinde, who compared them with the above genus or *Stelletta*.

Occurrence.—Norseman (G. J. Hinde).

Fam. STELLETTIDAE.

Genus STELLETTA Oscar Schmidt.

cf. *Stelletta reticulata*, Carter.

Hinde, 1910, p. 13. pl. 1. f. 32.

Observations.—A trifid spicule, with simple slightly curved and nearly horizontal head-rays has been compared with those of Carter's sp. from the South coast of Australia.

Occurrence.—Norseman (G. J. Hinde).

Genus ECIONEMA, Bowerbank.

Ecionema glauerti, sp. nov.

Plate VI., fig. 2.

Description of Holotype.—

The body of the sponge is of a slender cylindrical form, slightly curved, and apparently attached by an irregular, swollen base. The interpenetrating canals are numerously disposed over the weathered surface, whilst the long slightly curved acerate oxea average in length 3·5mm. These principal skeletal spicules give a fibrous and woody appearance to the fossil. Microrhabds numerous, slightly curved, with rounded ends or finely acerate. Other of the microscleres (smaller spicules) include sanidasters, which are irregularly rod-shaped and with a spiny surface, as well as numerous sub-spherical sphaerasters with short thorny processes. Occasionally the oxea are smooth or sparsely pitted.

Spicules of the protriæne type are common in the basal part of the sponge. Length of produced rhabdus 1·48mm. Length of cladi, 0·58mm., forming an angle of about 20° with the produced rhabdus.

The solidly spicular structure precludes this fossil body from being a cloacal tube. Length of sponge body, 44mm.; average diameter of cylindrical portion, 6mm.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection, H5. Holotype).

Fam. GEODIIDAE.

Genus EYRLUS Gray

Erylus, sp.

Hinde, 1910, p. 14. pl. 11. f. 2.

Observations.—Trifid spicules with a straight elongate shaft and with each of the head-rays bifurcated and horizontally extended are compared by Dr. Hinde with the Eocene genus *Erylus* Gray.

Occurrence.—Norseman (G. J. Hinde).

Genus CAMINUS O. Schmidt.

Caminus parvistoma, sp. nov.

Plate VI., fig. 3.

Description of Holotype.—Sponge massive and spreading, roundly lobulate, attached. Ossules small as compared with *C. sphæroconia* Sollas (1888, p. 214, pl. XXVII), situated at the summit of the lobes, with openings re-entrant and sharply rimmed; narrow incurrent canals leading into the oscules.

Incurrent pores conspicuously rimmed, situated in sieve structure, and revealed on worn surface as oblique channels.

Spicules.—Orthotriæne, with long stout axis and double divergent cladi; axis 1·8mm. in length. Numerous curved fusiform microrhabds are also present measuring 0·73mm. in length. Besides these are occasional spicules which are usually seen in *Cydonium*, namely globostellate and knobby forms, together with some trifid and nodulose spicules like those figured by Hinde (1910, pl. 11. f. 7, 8.) as "skeleton spicules of *Ragadinia*," a lithistid form.

Observations.—Triæne spicules with bifurcated head-rays such as seen in *Caminus parvistoma* were also noted by Hinde (1910, pl. 11, f. 2.) who, however, referred them to *Erylus*.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection $\frac{1}{3967}$, Holotype).

Caminus nitidus, sp. nov.

Plate VI., fig. 4.

Description of Holotype.—Sponge hemispherical, free or only slightly attached to extraneous objects. Oscules few, as sub-circular shallow cavities (circ. 8mm. in diameter), with fine grooves radiating from the interior. Pores rounded, numerous, having a diameter of circ. 2mm. Skeletal structure as in the preceding species but of a finer or closer texture.

Dimensions.—Holotype : diameter 33mm. ; height 22mm.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection, $\frac{1}{3988}$ Holotype).

Genus CYDONIUM Fleming.

Cydonium mulleri Fleming.

Geodia aff. *zetlandica* Johnston.

Hinde, 1910, p. 14, pl. 11, f. 6.

Observations.—Trifid spicules of this or an allied genus are recorded by Hinde from the Norseman deposit.

Occurrence.—Norseman (G. J. Hinde).

Cydonium ramuliferum, sp. nov.

Plate VI., fig. 5.

Description of Holotype.—Sponge cylindrical, sometimes flattened or tuberous, occurring in fasciculated masses. Individual branches measuring about 5cm. in length and about 1cm. in breadth. Preserved in a limonitic matrix, but still having the siliceous web preserved in part. The skeletal spicules are orthotriænes, and also large and small microrhabs. The latter are gently arcuate, fusiform and smooth, and usually with an axial canal ; they measure 0·18mm. in length.

Observations.—The grapnel spicules mentioned by Hinde (*loc. cit.* p. 14), as probably referable to the preceding form, *Cydonium* aff. *mulleri* were not seen in the present species.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection, $\frac{1}{3973}$, Holotype).

Order LITHISTIDA.

Fam. TETRACLADIIDAE.

Genus THEONELLA Gray.

cf. *Theonella swinhoei* Gray.

Hinde, 1910, p. 18. pl. 111. f. 2.

Observations.—Dr. Hinde has compared a dermal spicule having a short shaft and five horizontally extended rays, with that of the living sponge cited above, from Manila and Formosa.

Occurrence.—Norseman (G. J. Hinde).

Genus DISCODERMIA Bocage

Discodermia gigantea, sp. nov.

Pl. VII., fig. 6.

Description of Holotype.—This sponge is of very large size and compared with the known living forms. It is irregularly lobose, forming apparently a compound colony, the soma of which resembles depressed domes or lobes.

The process of petrifaction, so far as one can see, has resulted in the destruction of the ectosome, although in the surrounding mud are fragments of what may be dermal spicules, We have been unable, however, to find definite spicules like those figured by Dr. Hinde from the Norseman rock, which he has referred to the genus *Discodermia*. In the present specimen there is no sign of a pedicle, the base being flattened on the seat of attachment. The The worn condition of this sponge shows the pores very clearly. The ostia have an average diameter of 2mm. The pores are minute and scattered over the surface, measuring about 0·5mm. The ostia have a general radial arrangement from the centre of the base.

Structure of the Skeleton.—The body of the sponge has become opalized and solidified, but much of the skeletal structure is shown with its original porous character. The main skeletal mesh consists of more or less elongated tetracrepid desmas. Near the exterior of the skeleton there are numerous oxeas both straight and curved, averaging about 1·5mm. in length. Those spicules of the tetracrepid type closely resemble the skeleton spicules of *Discodermia* sp. figured by Dr. Hinde (1910, pl. 11. figs. 9, 10.), but in many cases they are much larger and more elongate in form.

Dimensions.—Greatest width, 27·5cm. ; Greatest height, 12·5cm.

Observations.—As to the form of this sponge the comparison may be made with the species described by Professor Sollas from Port Jackson, N.S.W., as *Discodermia discifurca*. The living species is about one third the diameter of the fossil. It also shows the mode of attachment by a flattened base rather than a pedicle. The cup-shaped habit of this species makes it different from the above fossil species in which there is very little evidence of cloacal cavities.

The tetracrepid desma of the living *D. discifurca* are much slenderer than those of the present fossil species, *D. gigantea*.

Occurrence.—Albany, W.A. (E. S. Simpson collection).

Discodermia tabelliformis, sp. nov.

Pl. VII., figs. 7, 8.

Description of Holotype.—Sponge massive, complanate, surface mamillated, with dense texture ; where abraded finely porous. Beneath the surface crust the sponge is closely perforated with fine vertical and sinuous pores. Skeletal spicules are of the type characteristic of the above genus, and are furcate, twisted and covered with small tubercles.

Microscleres, slender curved or bow-shaped oxea, 0·18mm. in length, and elongate-ovate microstrongyles, 0·045mm. in length.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection, $\frac{1}{3966}$. Holotype).

Discodermia retepora, sp. nov.

Pl. VII., fig. 9.

Description of Holotype.—Massive, of a compressed, more or less tabulate form, with an undulose surface. Pores large (circ. 3mm. in diameter). Skeletal mesh formed of strongyles with rounded centres and radiating cladi, the globular nuclei giving a finely beaded aspect to the desma.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection. $\frac{1}{3904}$. Holotype). A fairly abundant species.

Discodermia tumulosa, sp. nov.

Pl. VIII., fig. 10.

Description of Holotype.—Form of sponge, depressed to sub-globular, with surface rising into mamillated prominences. Ostia distinct, small (circ. 0·75mm. in diameter) and numerous.

Observations.—The skeleton resembles in many respects that of a typical living *Discodermia*, but in this variable species the ostia although small, are very distinct from the finer incurrent pores. *D. tumulosa* varies from the slightly mamillate to the coarsely globulose form. It is one of the more abundant species in this collection.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection, $\frac{1}{39063}$. Holotype).

Genus NEOSIPHONIA Sollas

Neosiphonia fungiformis, sp. nov.

Pl. VIII., figs. 11, 12 ; Pl. IX., fig. 13.

Description of Holotype.—The form of this sponge is somewhat depressed mushroom-shaped, with a rather expanded head and thickened pedicle, the latter being marked off from the main body of the sponge by a distinct but irregularly excavated sulcus on the under surface of the capitulum. In general outline the sponge is sub-pyriform and much depressed at the summit. The sides of the sponge are marked with a series of vertical fissures which commence at the base of the pedicle and pass over the periphery at the top, where they are lost in the central cloacal area at the summit. This central area at the top of the sponge occupies about half the entire diameter, and is covered with a large number of crowded tubular oscula which belong to the excurrent system. The sides of the sponge are also divided by a series of irregular, more or less horizontal, fissures which appear to be partly induced by shrinkage.

The basal view of the sponge shows a general radial structure, in which the skeleton is grouped along certain lines due to the close inter-growth or zygosis of the spicules of the desma. The diameter of the oscula have an average measurement of 1·25 mm.

Dimensions.—Greatest height, 51mm. Greatest width, 65mm.

Structure of the Skeleton.—The holotype described above is finely preserved and the skeletal mesh shows distinctly on the surface, Owing to fossilisation the spicules other than the megascleres seem to have been lost. The megascleres of the desma measure 0·94mm. in length, and 0·42mm. in width.

Observations.—The genus *Neosiphonia* was founded on a living species, *N. superstes*, dredged from a depth of 315 fathoms in coral mud off Matuka, Fiji Islands. It was collected during the voyage of the "Challenger" and described by Prof. W. J. Sollas (Sollas, 1888, p. 299–301, Pl. XXXII. figs. 7–12). In his remarks on the living specimen Prof. Sollas states that the sponge consisted merely of the skeleton with the exception of a few shreds of dermal material, and it was from this that he obtained the dermal spicules which in the present fossil example seem to be absent.

As Prof. Sollas has already remarked, this genus is extremely interesting from the fact that it appears to be a surviving representative of the common *Siphoniæ* and *Jereæ* of the Mesozoic formations and especially of the Chalk. The present species forms an important link between the living and the cretaceous species in point of age.

Occurrence.—Clay Pit, near Racecourse, Albany. W.A. Holotype (E. S. Simpson collection).

Also Hamersley River District, W.A. (W.A. Geol. Surv. collection paratype $\frac{1}{3854}$.) Variable forms, some examples being more fig-shaped than the type.

Neosiphonia glauerti, sp. nov.

Pl. IX., fig. 14.

Description of Holotype.—A funnel shaped sponge, conical, with a bluntly apical pedicle. Cloacal cavity wide, fairly deep, with gently concave sides. Numerous small oblique openings into the cloacal cavity (postica). Sides of sponge body having numerous small rounded pores (ostia). Skeletal mesh consisting of closely welded dichotriaenes. Surface, with dermal spicules, chiefly microxeas and microrhabds.

Dimensions.—Height of sponge, 53mm. ; greatest diameter across cavity at summit, 42mm.

Occurrence.—Hamersley River District, (W.A. Geol. Surv. collection [illegible]. Holotype).

Genus THECOSIPHONIA Zittel

Thecosiphonia lobosa, sp. nov.

Pl. IX., fig. 15.

Description of Holotype. Sponge, irregularly lobose, constricted medially in the holotype ; varying in slope to depressed conical. Dermal layer consisting of small clasping rhabdocrepid desma, as in the living *Pleroma.* The skeletal portion consisting of a coarse mesh of nodular spicules with smooth divergent arms.

Several cloacal openings occur on the summit of the sponge, as wide shallow depressions, perforated by excurrent canals having a diameter of about 3 to 4 mm. Incurrent canal openings numerous ; apertures circular to ovoid, 1mm. in diameter.

Observations. Both in general form and skeletal structure this Tertiary sponge resembles the well-known cretaceous genus with its typical species *T. turbinator* Hinde, from the Upper Chalk of Wiltshire, England.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection, Holotype $\frac{1}{3969}$).

Genus THAMNOSPONGIA Hinde

Thamnospongia neoclavellata, sp. nov.

Pl. IX., fig. 16.

Description of Holotype.—Sponge: sub-cylindrical, rather lobose and wrinkled, Surface covered with a dermal layer ; bearing short blunt arms (eight in type), which are generally broken, thus revealing the coarser pores (ostia) of the inner skeletal structure. The desmas are tetracvepid and form a close mesh-work of the endoskeleton, perforated by fine, rounded pores. Amongst the spicules of the dermal layer were noticed spirasters and microxea.

Dimensions.—Length of holotype, 50mm. ; greatest width, 20mm.

Observations.—In general form, as well as in structure, the above species closely approaches *Thamnospongia clavellata* (Benett) from the Upper Chalk of Wiltshire (Hinde, 1883, p. 79, pl. XVIII. f. 2, 2*a*, *b*).

Occurrence.—Moderately common. Hamersley River District, W.A. (W.A. Geol. Surv. collection, Holotype $\frac{H}{19}$).

Thamnospongia subglabra, sp. nov.

Pl. IX., figs. 17, 18 ; Pl. X., fig. 19.

Description of Holotype.—Holotype sub-cylindrical, with verrucose or pustulate surface. Paratype more or less compressed cylindrical, with two branches. Surface moderately smooth to even, covered with fine pores. Indication of cloacal tube at end of branches.

Dimensions.—Length of holotype, 75mm. ; greatest thickness, 20mm. Length of paratype 52mm.

Observation.—The numerous examples in the Glauert collection do not show any dermal layer. The porous character of the skeletal mesh is finer, whilst the ostia are smaller than usual.

Comparison is suggested with *Thamnospongia glabra* Hinde (Hinde 1883 p. 79. pl. XVII. f. 5 and *5a c*). This latter species is found in the Upper Chalk of Beehampton, Wiltshire, England. Its bushy manner of growth indicates that the present Tertiary species had a similar habit and that the fossil remains in this collection are the separated branches of the ramose sponge body.

Occurrence.—Hamersley River District W.A. (W.A. Geol. Surv. collection. Holotype $\frac{H}{1}$; Paratype $\frac{F}{16}$).

Genus RAGADINIA Zittel

Ragadinia placentiformis, sp. nov.

Pl. X., fig. 20.

Description of Holotype.—Sponge, when complete, platter-shaped, with an undulose surface. Layers of expansive growth marked by concentric, curved grooves. Skeletal mesh formed of tuberculate strongyles, closely fused. Abundant microrhabds seen on disintegrating the tissue ; these are slightly curved, cylindrical, smooth and generally roundly ended ; they average 0·34mm. in diameter.

Dimensions.—Greatest diameter of specimen, 10cm. Thickness of cup, circ. 7mm. Diameter of complete cup, circ. 12cm.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection, Holotype $\frac{1}{3981}$).

Fam CORALLISTIDAE

Genus CORALLISTES O. Schmidt.

? Corallistes sp.

Observations.—A dermal spicule with a short shaft and six horizontally extended rays has been figured by Dr. Hinde (Hinde, 1910, p, 17. pl. III. f. 1.) as referable to *Corallistes* or another genus.

Occurrence.—Norseman (G. J. Hinde).

Fam. ANOMOCLADIIDAE.

Genus VETULINA O. Schmidt.

Vetulina sp.

Observations.—" A spicule with four or five rays extending in different directions from a definitely thickened centre " is figured by Dr. Hinde (1910, p. 18. pl. II. fig. 11) who compares it with similar spicules from the Miocene of Oamaru, New Zealand.

Occurrence.—Norseman (G. J. Hinde).

Genus PLATYCHONIA Zittel.

Platychonia tertiaria, sp. nov.

Pl. X., fig. 21.

Description of Holotype.—Body of sponge complanate, encrusting, with external surface undulate and cuspid at edges. The upper weathered surface shows a well defined system of cloacal pores radiating outwardly from the base. Skeleton on weathered surface seen as a closely welded mass of globular spicules (megascleres), with 4 to 7 or more radiating arms. Microscleres represented by short oxea and microstrongyles like those seen in the living genus *Azorica*.

Observations.—This is an interesting link with the Liassic and Jurassic sponges of Europe, belonging to the same genus.

Occurrence.—Hamersley River District, W.A. (W.A. Geol. Surv. collection, Holotype $\frac{1}{3990}$).

Genus VERRUCULINA Zittel.

Verruculina albanyensis, sp. nov.

Pl. XI., fig. 22.

Description of Holotype.—Sponge (preserved in limonite), funnel-shaped, compressed. Dermal surface showing minute pores, and where worn away the ostia radiating from the base to the rim. Internal face of cup with fine pores and scattered ostia, the orifices of which are surrounded by raised rims.

The megascleres in the skeletal tissue of this fossil are seen to be similar to those figured by Dr. Hinde, from *Verruculina seriatopora* (Reuss), from the Upper Chalk of Sudmerberg (Hinde 1883, p. 36. pl. III. f. 4).

Dimensions.—Height of cup, 56mm.; approximate breadth at opening, 64mm.; narrow diameter of cup, 32mm. Width of ostia, 1·75mm.

Occurrence.—Hill, 1 mile from Warring Homestead, Albany, W.A. (Glauert collection; Holotype $\frac{1}{4134}$).

Class **HEXACTINELLIDA.**

Fam. ROSSELLIDAE.

Genus ROSSELLA Carter.

Rossella aff *Antarctica* Carter.

Rossella sp.

Hinde, 1910, pp. 19, 20. pl. III. f. 12–14.

Observations.—Dermal umbrella spicules figured by Hinde from the Norseman material are compared by him to those seen in *Rossella antarctica* Carter, but differing in being smaller and in having a patagium connecting the rays, as seen in various Cretaceous species.

Occurrence.—Norseman (G. J. Hinde).

Fam. MAEANDROSPONGIDAE.

Genus DACTYLOCALYX Stutchbury.

Dactylocalyx simpsoni, sp. nov.

Pl. XI, fig. 23.

Description of Holotype.—The actual form of the sponge is somewhat doubtful since only the branching portions remain. It may have been of a

low compact funnel-shape when complete, but is now represented by two main portions which show a characteristic canal system of which the tubes measure from 1·5mm. in diameter. The body of this sponge when complete probably had a diameter of 4·5cm. Only the internal mesh work of the sponge remains, but it shows such close resemblance with that of *Dactylocalyx patella*, Schulze, as to make the comparision at least generic (Schulze, F.E. 1887, p. 350. pl. C.). The tubes of the sponge body are smaller than that of the living species. They appear in some instances to run parallel for some distance and then to divaricate. The natural surface of the sponge is wanting, apparently being lost by partial decompositions in the matrix. The framework of the sponge in the main portion shows square meshes more or less regular, and especially in those portions nearest the walls of the tubes where in transverse section they seem to form a concentric structure. Portions of the dictyoninal skeleton in the neighbourhood of the canals are seen to carry sharp conical bosses which project radially into the lumen of the canals. These conical projections of the skeletal mesh are beset with fine pointed tubercles, as in the recent species which was dredged off the coast of Portugal and S.W. of the Bermudas from a depth of 1,075 fathoms by the Challenger.

Occurrence.—Albany, W.A. (E. S. Simpson collection).

Class **ECHINOIDEA.**

Order CIDAROIDA.

Fam. CIDARIDAE.

Genus PHYLLACANTHUS Brandt.

cf. *Phyllacanthus* sp.

Observations.—Impression of a cidaroid spine, the ornament of which represents that of the above genus.

Occurrence.—Albany. (Jutson collection).

Order SPATANGOIDEA.

Fam. SPATANGIDIEA.

Genus HEMIASTER Desor.

Hemiaster sp.

Observations.—The larger example, labelled No. 309 (1) from the Glauert collection, is a cast, much crushed, but still showing the high posterior vertex. As regards the characters of the ambulacral area, the anterior furrow is moderately deep, but not so constricted as in *Hemiaster planedeclivis.* Moreover the outline of the test (ambitus) is more circular than in that species.

The second and smaller specimen, No. 309 (2), has the ambulacral system closely comparable with Gregory's *Hemiaster planedeclivis*, but allowing for crushing the posterior vertex is not so high. The outline of the test of this form is more heart-shaped than the first specimen referred to. It agrees generally in character with a specimen from Waurn Ponds, Victoria, in the National Museum collection.

Occurrence.—Cape Riche, Albany District. (Glauert collection.)

Genus SCHIZASTER Agassiz.

Schizaster sp.

Observations.—In the Jutson collection there occur four specimens of an undescribed form referable to the above genus. They are all in form of casts, and are distorted in various ways by local crushing. There are two

additional specimens in the Glauert collection, Nos. 5718 and 405, from the same locality. Since the characters are wanting, which can be used in a specific sense on account of the absence of the test, the generic reference only is given. At the same time, it may be remarked, that from Table Cape and Torquay there appears to be an identical species, in the National Museum collection.

The features of the casts, taken *inter alia*, may be given as follows:— The test is more or less cordate; the ambulacral furrows are deep, especially the anterior by which the ambitus is distinctly notched. The anterior lateral furrows are divergent at a high angle, whilst the posterior pair are much shorter and less strongly developed. The peristome is strongly lipped. The periproct is possibly transversely ovate.

Dimensions.—One of the least crushed specimens measures 48 mm. in ant-posterior direction and 41 mm. at right angles.

Occurrence.—Cape Riche (Glauert & Jutson collection).

Genus EUPATAGUS Agassiz

? *Eupatagus* sp.

Observations.—A cast of the test of a tumid ovoid shape with indications of a flush ambulacral system, may be referable to this genus.

Occurrence.—Cape Riche (Jutson collection).

Class **POLYZOA.**

Order CHEILOSTOMATA.

The following have been determined from material in the Simpson collection from Norseman:—

Macropora clarkei (T. Wds.), Also in the Albany Beds (Simpson collection).

Acropora gracilis (M. Edws.).

Occurrence.—Norseman, in a silicified and partly opalised bed (Simpson collection).

In addition, Prof. J. W. Gregory (1916, p. 320–1) gives the following list from the same locality:—

Membranipora delicatula (Busk).
Cellaria rigida McG.
Schizoporella convexa McG. = *Lacerna convexa* (McG.).
Macropora clarkei (T. Wds.).
Schismopora modesta McG.

Class **BRACHIOPODA.**

Order TELOTREMATA.

Fam. TEREBRATULIDAE.

Genus TEREBRATULA Klein.

Terebratula aldingae Tate.

Observations.—A cast of this interesting species is comparable with those forms that are restricted to the Aldingan (South Australia) and Cape Otway (Victoria) series.

Occurrence.—Albany (Jutson collection).

Terebratula tateana T. Woods.

Observations.—A compressed cast is comparable with the above specie

Occurrence.—Albany (Jutson collection).

Fam TEREBRATELLIDAE.

Genus MAGELLANIA Bayle.

Magellania insolita Tate.

Observations.—A specimen collected by Dr. Simpson is a cast with part of the shell attached and replaced in silica embedded in the polyzoal rock of Norseman.

Occurrence.—Norseman (Simpson collection).

Magellania pectoralis (Tate).

Observations.—A fairly well-preserved cast of this species occurs in which the characters of the small foramen and the produced beak are well shown. It is interesting to note the previous restricted occurrence of this species, only at Aire Coast, Victoria, and Aldinga and Happy Valley, South Australia. This specimen has a total length of 56mm.

Occurrence.—Cape Riche (Glauert collection).

Class **PELECYPODA.**

Order PRIONDESMACEA.

Fam. ARCIDAE.

Genus ARCA Lam.

Sub-genus BARBATIA Gray.

Arca (Barbatia) cf. *consutilis* (Tate).

Observations.—The two examples of this species are represented by casts of the interior of the valve, in chert. The contour of these shells practically confirms the identity with the above species.

Occurrence.—Warriup Homestead, Albany, and Hassell's Homestead. (Glauert collection).

Arca sp.

Observations.—This fossil is an internal cast of a species having a strongly angulated umbonal ridge, and in general character appears to be related to both *A. celleporacea* and *A. simulans.*

Occurrence.—Albany (Jutson collection).

Genus GLYCYMERIS Da Costa

Glycymeris maccoyi (Johnston).

Observations.—Two examples occur both in the form of internal casts. In one specimen, from near Mt. Manypeak, the matrix shows the costation of the medium layer of the shell, possibly indicating partial solution during fossilisation of the internal layer of the original shell. The previous localities at which this species has occurred are Table Cape, Tasmania, and Ooldea (South Australia).

Occurrence.—Cape Riche (Jutson collection), and coast near Mt. Manypeak (Glauert collection).

Fam. PECTINIDAE.

Genus CHLAMYS Bolten.

Chlamys aldingensis (Tate).

Observations.—A cast of valve showing the characteristic disappearance of the costation towards this hinge line.

Occurrence.—Albany (Jutson collection).

Chlamys flindersi (Tate) sp.

Observations.—Internal cast of valve shows typical angulated rib of *C. flindersi*, the costae numbering about 32 and are practically smooth. It

is separated from *C. sturtianus* by less divergent type of rib, and from *C. aldingensis* by the few ribs and more divergent type of costation.

Occurrence.—Albany (Jutson collection).

Fam. DIMYIDAE.

Genus DIMYA Rouault.

Dimya dissimilis (Tate).

Observations.—A cast in the soft sponge bed of Albany shows the impression of the upper valve of *Dimya dissimilis*. This specimen was tentatively determined as cf. *Chama lamellifera* in our previous report (A.A.A.S., 1926).

Occurrence.—Albany (Jutson collection).

Fam. MYTILIDAE.

Genus LITHOPHAGUS Megerle.

Lithophagus sp.

Observations. The above specimen is in the form of an ironstone cast. The nearest related species is *Lithophagus latecaudatus* Pritchard, from the Lower Miocene of Torquay, Victoria, but differs from that species in having a longer and more parallel-sided shell, and a sharper umbonal keel. Length of shell-cast, 56mm. Greatest width, circ. 21mm.

Order TELEODESMACEA.

Fam. LUCINIDAE.

Genus CODAKIA Scopoli.

Codakia planatella (Tate).

Observations.—Although in the form of casts, the specimen can be identified with the above species which has only been recorded from Table Cape, Tasmania, as *Lucina planatella*.

Occurrence.—Balladonia limestone, Eucla district (Glauert collection, Nos. 3253 to 3256).

Fam. CARDIIDAE.

Genus CARDIUM Linné.

Cardium arcaeformis, sp. nov.

Pl. XI., figs. 25, 26, 27.

Description.—Valve, subquadrata, ventral edge roundly narrowing towards the front, produced posteriorly and truncally angulate towards the posterior angle. A rounded posterior umbonal ridge apparent ; shell strongly inflated and with prominent umbones. Ornament consisting of 25 ribs. Riblets with a central crenulated ridge and two lateral ones. Intercostal spaces excavated, relieved with concentric growth-lines.

Dimensions.—Length of shell, 15mm. Height, 15·5mm. Depth of valve, 7mm.

Observations.—One of the nearest related forms appears to be *Cardium exasperatum* Reeve, from Swan River, W.A. In form *C. arcaeformis* differs in being inflated, in its greater height, more oblique and more decided umbonal slope.

Occurrence.—Albany (Glauert collection, No. 6048).

Genus HEMICARDIUM Cuvier.

Hemicardium sp. Pl. XI., fig. 24.

Observations.—The present example is a cast which has been slightly crushed, but showing the general form of the united valves, and also some of

the original ornament which consists of numerous, closely set and flattened radiating ribs. In the absence of shell characters only the relationship of this form can be pointed out. The nearest related species is *Hemicardium nivale* (Reeve) from the Island of Corrigidor, Philippines, which was dredged from coral sand at the depth of 8 fathoms.

Occurrence.—Cape Riche (Jutson collection).

Fam. MACTRIDAE.

Genus MACTRA Linne.

Mactra axiniformis (Tate).

Observations.—This species is represented by a cast showing the main characters of the interior of the valves. It is important to note that the only locality previously recorded for this species is Torquay, Victoria.

Occurrence.—Balladonia limestone, Eucla district (Glauert collection, No. 3250).

Class **GASTEROPODA.**

Order ASPIDOBRANCHIA.

Fam. PATELLIDAE.

Genus CELLANA Adams.

Cellana jutsoni sp. nov.

Pl. XI., fig. 28.

Description of Holotype.—This is based on a squeeze in plasticene, of a mould of the shell in fine spicular ooze. The shell is ovately oblong, moderately depressed and with a fairly sharp apex situated about one-third from the anterior margin. Seen edgewise, the curvature of the shell from the apex to the posterior margin is strongly convex. Anteriorly, there is a slight depression under the apex. The lateral slopes of the shell are depressed-convex resulting in an obscure ridge extending from the apex to the posterior margin of the shell. The median area of the shell surface is almost smooth and marked by occasional concentric growth-lines. Towards the margin is developed a series of thin and sharp costae, numbering about 46 in the entire circumference. Close to the margin of the external surface these costae are crossed by very fine concentric lines.

Dimensions.—Longest diameter, 19·5mm. ; shortest, 14·5mm. Height at apex, 3·25mm.

Observations.—*Cellana jutsoni* appears to be quite distinct from any of the Australian species living or fossil. In its generic characters it is referable to *Cellana*. A form which may be distantly related to it is the Kalimnan species, *Cellana hentyi* (Chapman & Gabriel, 1923, p. 23, pl. I., fig. 2), from the Lawer Pliocene of the Grange Burn, near Hamilton, Victoria. That species differs, however, in the stronger costation of the shell and its heavy build.

Occurrence.—Holotype, Albany (Jutson collection).

Order CTENOBRANCHIATA.

Fam. MATHILDIIDAE.

Genus MATHILDA Semper.

Mathilda pagoda, sp. nov.

Pl. XI., figs. 29, 30.

Description of Holotype.—Aldinga Bay (Dennant collection, National Museum, Melbourne). Shell turreted, somewhat twisted in axis of growth, whorls angulate, ornamented with 3 lirate nodules bands, the basal one

being much stronger than the other two and more distinctly beaded. This principal band is just above the suture line and gives a geniculate appearance to the whorl. Numerous strong threads vertically crossing the lirae and at the point of junction becoming thickened.

Dimensions.— Length of Holotype, minus brephic stage, 14 mm. Width at base, 6 mm.

Description of Paratypes.— (a) Aldinga Bay (from Dennant collection). Specimen showing the perfect apex consists of 5 whorls in the neanic stage and the typical embryonic protoconch, and the succeeding brephic whorl, which is smooth.

(b) (Jutson collection). A wax squeeze of a mould shows the original shell to have been of a much heavier and larger type than the two from Aldinga Bay. Length, circ. 27 mm. and circ. 11 mm. at base.

Observations.—In its generic characters *M. pogoda* resembles *M. decorata* Hedley, but differs specifically in the longer embryonic stage and in the distinctly angulate whorls. This form from Aldinga Bay was listed from Adelaide by Tate and Dennant (1896, p. 127), under the manuscript name of *Colina pagoda.*

Occurrence.—Holotype, Aldinga Bay, South Australia (Dennant collection, National Museum, Melbourne, Reg. No. 13676). Paratype: Albany (Jutson collection).

Fam. Xenophoridae.

Genus xenophora Fischer.

Xenophora cf. *Tatei* Harris.

Observations.—This example is equal in size to a large specimen in the National Museum referred to *Phorus tatei*, from the lowest beds of the River Murray Cliffs near Morgan.

Occurrence.—Brick Works, 3 miles N.E. Albany (Glauert collection).

Fam. Cerithiidae.

Genus potamides Brongn.

Potamides nullarboricum, sp. nov.

Pl. XI., figs. 31, 32, 33.

Description of Holotype.— (From the Dennant collection, National Museum, Melbourne). Shell turreted, 10 whorls, slightly inflated, depressed at the sutures, the completed shell having about 18 whorls, including 3 in protoconch. Surface of whorls ornamented with about 13 riblets moderately sharp and slightly curved, which increase in width at the junction with the suture, giving an impression of a sutural band. The surface of the shell is also ornamented with fine spiral striations which cross the ribs. Mouth of shell subquadrate, base terminating in a short canal.

Description of Paratypes.—One of these specimens from the Dennant collection (Pl. VI., fig. 32) has 9 costate whorls and a smooth protoconch with 3 turns. The second specimen from Cape Riche (Jutson collection) of which a figure of a wax impression is given, is a mould of the shell showing the surface ornament very well preserved.

Dimensions.—Length of holotype, imperfect, 33·5 mm. Greatest width at base of shell, 12 mm.

Observations.—The above species is fairly common in form of casts and moulds in the fine siliceous rock from Cape Riche. Since there was already examples showing the shell in the Dennant collection labelled with the manu-

script name, *Potamides nullarboricum* by Tate, the name has been retained for the present species.

Occurrence.—Holotype: Lower beds, Aldinga, South Australia (Dennant collection, National Museum, Reg. No. 13674). Paratype: (a) Aldinga (Dennant collection, Reg. No. 13675); (b) Cape Riche (Jutson collection).

Fam. STROMBIDAE.

Genus SERAPHS Montfort.

Seraphs sp.

Observations.—An identical form has been described by Harris (1897, p. 218) from the Tertiary of the Nullabor Plains, South Australia. He stated that it is closely allied to the European Eocene species, *S. fusiformis* (Lam.).

Occurrence.—Bremer Bay (Glauert collection).

Fam. CYMATIIDAE.

Genus CYMATIUM Bolton.

Cymatium cribrosum (Tate).

Observations.—This identification is founded on a well preserved mould which shows characteristic lirate ornament showing the two strong bands on the shoulder of the whorls; also the attenuated spire terminating in 2½ rounded whorls. This species has hitherto been recorded by Tate from the clayey greensands of the Adelaide Bore, whilst there are numerous specimens in the Dennant collection, National Museum, Melbourne, from Cape Otway, Victoria.

Occurrence.—Albany (Jutson collection).

Fam. FUSINIDAE.

Genus FUSINUS.

Fusinus simulans (Tate).

Observations.—This form ranged from the Upper Oligocene to the Middle Miocene in Victoria.

Occurrence.—Albany (Jutson collection).

Fusinus senticosus (Tate).

Observations.—This species, of which moulds are here found, have a range from Upper Oligocene to Middle Miocene in Victoria. In South Australia it occurs in the Middle Miocene, in Tasmania in the Lower Miocene of Table Cape.

Occurrence. Albany (Jutson collection).

Genus SIPHONALIA Adams.

Siphonalia tatei (Cossman).

Observations.—Well preserved moulds of this species, which ranges from Upper Oligocene and Middle Miocene, were found in the spicule-bearing rock.

Occurrence.—Albany (Juntson collection).

Fam. VOLUTIDAE.

Genus VOLUTA Linné.

Voluta sp.

Observations.—A somewhat crushed cast of a large volute which bears a close resemblance to *V. atkinsoni*, Table Cape, Victoria.

Occurrence.—Brick Works, 3 miles N.E. of Albany (Glauert collection).

Genus SCAPHELLA Swainson.

Scaphella pagodoides (Tate).

Observations.—This form is characteristic of the Lower Miocene, both in South Australia and Victoria.

Occurrence.—Albany (Jutson collection).

Fam. OLIVIDAE.

Genus OLIVELLA Swainson.

Olivella angustata (Tate).

Observations.—This species, here represented by moulds, has hitherto been restricted to the Lower Miocene of Muddy Creek, Victoria.

Occurrence.—Albany (Jutson collection).

Fam. CONIDAE.

Genus CONUS Linné.

Conus dennanti (Tate).

Observations.—This form ranges from the Oligocene to the Lower Miocene of Victoria. The present specimen is a distorted cast, but quite specifically identifiable.

Occurrence.—Brick Works, 3 miles N.E. of Albany (Glauert collection).

Class **CEPHALOPODA.**

Order NAUTILOIDEA.

Fam. CLYDONAUTILIDAE.

Genus ATURIA Bronn.

Aturia australis (McCoy).

Observations.—This specimen is a partial cast of the shell, representing about two-thirds of the contour. An *Aturia* from Albany was described in detail some years ago by R. Bullen Newton (Newton, 1919), and was ascribed by that author to *A. aturi* (Basterot).

Occurrence.—Brick Works, 3 miles N.E. of Albany (Glauert collection)

Fam. NAUTILIDAE.

Genus NAUTILUS Linné.

Nautilus geelongensis (Foord).

Observations.—The two specimens from the Jutson collection are in the form of casts, and from the contour in the oral aspect appear to be referable to this species.

Occurrence.—Albany (Jutson collection).

Location of Types.

All those types belonging to the W.A. Geological Survey collection have been returned to Perth. Those from the Jutson collection have been presented by J. T. Jutson to the National Museum, Melbourne.

IV. AGE OF BEDS AND SUMMARY.

(1) The important and in many ways unique sedimentary formation in the southern part of Western Australia, named the Plantagenet Series, by Jutson and Simpson, occurs in depressions laid down on a granite platform.

(2) The remarkable variation in the kinds of sedimentation of these Tertiary beds gives the Plantagenet Series an additional interest, for they comprise a rich sponge fauna, besides an accumulation of spicular muds, containing casts and moulds of mollusca and echinoids together with a fair number of well preserved leaves that have been carried down into these marine sediments.

(3) With regard to the age of the Plantagenet Series, the evidence of the mollusca is the most weighty, since the sponges, although numerous, represent a facies which is almost unique in our fossil beds, and which also contain more archiac genera than are usually found in beds of this age in any part of the world. Some of these fossil genera date back to the Jurassic and Cretaceous in Europe, whilst in other cases there are forms linking up the Cretaceous in Europe with the sponge beds being laid down at the present time, notably in the case of *Neosiphonia.*

(4) Certain of the fossil leaves here recorded had been previously met with through the work of the Horn Expedition to Central South Australia, which at the time were thought to be of Cretaceous age, but which are now accepted as Miocene.

(5) In 1915, J. T. Jutson and E. S. Simpson, had written that they believed that the beds would be ultimately determined as of Miocene Age. This statement was not published until two years later. In 1916, J. W. Gregory and A. E. Kitson, determined the age of the beds as Miocene, on the polyzoa and mollusca. In 1926, after a preliminary examination, the present authors expressed their view that the fauna showed an age about the Middle Miocene and a connection with that of Table Cape, Tasmania and South Australia.

(6) The present detailed study shows that from the mollusca alone, the age of this Plantaganet Series can be definitely stated as of Lower Miocene age. Since writing our preliminary paper now we have obtained proof of a slightly greater antiquity of the lower beds at Table Cape, for they in turn, can be linked up with those of Torquay in Victoria, also definitely Lower Miocene.

COMPLETE LIST OF FOSSILS COMPRISED IN THE PLANTAGENET SERIES.

Abbreviations used in regard to localities : —

A = Albany ; B = Balladonia limestone ; H = Hamersley River ; R = Cape Riche ; BW = Brick Works, 3 miles N.E. of Albany ; SC = Sugar Bag Creek ; W = Warriup Homestead ; WH = Hill, 1 mile from Warriup Homestead ; LB = Little Bluff ; HH = Hassell's Homestead ; M = Mt. Manypeak ; BB = Bremer Bay ; HR = Hassell's Road ; C = Near Cheyne Beach ; K = King River ; N = Norseman.

Plantae :

Agathis cf. intermedia Ett.	R
Nothofagus wilkinsoni Ett.	R
Bombax mitchelli Ett.	R
,, sturtii Ett.	R
cf. Grevillea	A

Foraminifera :

Marginopora vertebralis, Q. & G.	B

Spongida :

Tethyia aff. robusta Bowerbank	N
Latrunculia sp.	N
Halichondria sp.	N
Petrosa cf. variabilis Ridley	N
Desmacidon (Homoeodictya) grandia Ridley & Dendy	N
Forcepia cf. crassanchorata Carter	N
Strongylophora sp.	N
Craniella sp.	N
cf. Stelletta reticulata Carter	N
Ecionema glauert sp. nov.	H
Erylus sp.	N
Caminus parvistoma sp. nov.	H
,, nitidus sp. nov.	H
Cydonium mulleri Fleming	N. & H.
,, ramuliferum sp. nov.	H
Discodermia gigantea sp. nov.	A
,, tabelliformis sp. nov.	H
,, retepora sp. nov.	H
,, tumulosa sp. nov.	H
Neosiphonia fungiformis sp. nov.	H. & A.
,, glauerti sp. nov	H
Theonella swinhoei Gray	A
Thecosiphonia lobosa sp. nov.	H
Thamnospongia neoclavellata sp. nov.	H
Thomnospongia subglabra sp. nov.	H
Ragadinia placentiformis sp. nov.	H
? Corallistes sp.	N
Vetulina sp.	N
Platychonia tertiaria sp. nov.	H
Verruculina albanyensis sp. nov.	W
Rossella aff. antarctica Carter	N
Dactylocalyx simpsoni sp. nov.	A
Sponge spicules, indeterminate	LB
Spicules in chert	SC

Echinoidea :

Phyllacanthus sp.	A
Hemiaster sp.	R
Schizaster sp.	R
? Eupatagus sp.	A

Polyzoa :

Cellaria rigida McG	N
Membranipoda delicatula (Busk)	N
Macropora clarkei (T. Wds.)	N
Schismopora modesta McG.	N
Lacerna convexa (McG.)	N
Acropora gracilis (M. Edws.)	N
Lepralia sp.	R
Schizellozoon sp.	C

Brachiopoda :

Terebratulina aldingae Tate	A
Terebratula tateana T. Wds.	A
Magellania insolita (Tate)	N
,, pectoralis (Tate)	R
,, cf. sufflata (Tate)	B
? Magellania sp.	A

Pelecypoda :

Nucula obliqua Lam.	R
Cucullaea corioensis McG.	R
Limopsis sp.	R

Pelecypoda—continued.

Arca (Barbatia) cf. cainozoica Tate	A
,, ,, sp.	HH. A. & W
,, ,, cf. consutilis Tate	HH. & W.
Glycymeris maccoyi (Johnston)	M. & R.
Pteria (Meleagrina) crassicardia Tate	R
Hinnites sp	HH
Chlamys aldingensis (Tate)	A
,, flindersi (Tate)	A
,, eyrei (Tate)	A
,, murrayana (Tate)	R
,, praecursor (Chapm.)	B
,, sturtianus (Tate)	R
Dimya dissimilis Tate	A
Lima bassi T. Wds.	N
Lithophagus sp.	K
Crassatellites ? sulcatus Sol.	BB
Venericardia spinulosa (Tate)	N
,, scabrosa (Tate)	A., W. & SC
,, cf. scabrosa (Tate)	N
,, cf. delicatula (Tate)	SC
,, cf. gracilicostata (Tate)	W
Codakia planatella (Tate)	B
cf. Diplodonta sp.	BB
? Dosinia johnstoni Tate	HH
cf. Dosinia sp.	BB
Cardium arcaeformis sp. nov.	A
,, aff. cuculloides Tate	A. & B.
,, cf. pseudomagnum McCoy	B
Hemicardium sp.	R
Callanaitis cainozoicus (Tate)	HR. & B.
? Callanaitis sp.	W
Clausinella allporti (T. Wds.)	R
cf. Clausinella sp.	R
Katelysia sp.	R
Antigona cf. hormophora (Tate)—	K
Meretrix sp.	R
cf. Meretrix sp.	B
Tellina sp.	K
Mactra axiniformis Tate	B
Corbula sp.	N
Kuphus sp.	B

Gasteropoda :

Cellana justoni sp. nov.	A
Natica hamiltonensis Tate	A
Xenophora cf. tatei Harris	BW
Turritella tristira Tate	N
Mathilda pagoda sp. nov.	A
Potamides nullarboricum sp. nov.	R
Seraphs sp.	BB
Cypraea sp.	A
,, subsidua Tate	A
Trivia sp.	HR
Phalium cf. textile (Tate)	R
Cymatium cribrosum (Tate)	A
Siphonalia tatei Cossman	A
Fusinus senticosus (Tate)	A
,, simulans (Tate)	A
? Fusinus sp.	BB
Lyria sp.	A
Voluta sp.	A
Scaphella pagodoides (Tate)	A
,, tateana (Johnston)	B
Olivella angustata (Tate)	A
Conus dennanti Tate	BW
,, ligatus Tate	BB
Semiactaeon microplocus Cossm.	N

Cephalopoda :

Aturia australis McCoy	BW
Nautilus geelongensis Foord	A
Nautilus sp.	A

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EXPLANATION OF PLATES.

PLATE VI.

Fig. 1.—**Bombax sturtii,** Ett., Cape Riche. Nat. size.
Fig. 2.—**Ecionema glauerti,** sp. nov. Hamersley River District. Holotype, Circ. nat. size.
Fig. 3.—**Caminus parvistoma,** sp. nov. Hamersley River District. Holotype, Circ. nat. size.
Fig. 4.—**C. nitidus,** sp. nov. Hamersley River District. Holotype, X $\frac{4}{3}$.
Fig. 5.—**Cydonium ramuliferum,** sp. nov. Hamersley River District. Holotype, Circ. nat. size.

PLATE VII.

Fig. 6.— **Discodermia gigantea,** sp. nov. Albany. Holotype. $\frac{2}{5}$ nat. size.
Fig. 7.—**D. tabelliformis,** sp. nov. Hamersley River District. Holotype, $\frac{3}{4}$ nat. size.
Fig. 8.—**D. tabelliformis,** sp. nov. Sectional view of Holotype. Circ. nat. size.

PLATE VIII.

Fig. 9.—**Discodermia retepora,** sp. nov. Hamersley River District. Holotype. Nat. size.
Fig. 10.—**D. tumulosa,** sp. nov. Hamersley River District. Holotype. Nat. size.
Fig. 11.—**Neosiphonia fungiformis,** sp. nov. Clay Pit near Racecourse, Albany. Holotype. Nat. size.
Fig. 12.—**N. fungiformis,** sp. nov. Side view of wall of Holotype. X$\frac{3}{2}$.

PLATE IX.

Fig. 13.—**Neosiphonia fungiformis,** sp. nov. Hamersley River District. Paratype. Nat. size.
Fig. 14.—**N. glauerti,** sp. nov. Hamersley River District. Holotype. Nat. size.
Fig. 15.—**Thecosiphonia lovosa**, sp. nov. Hamersley River District. Holotype. Circ. nat size.
Fig. 16.—**Thamnospongia neoclavellata,** sp. nov. Hamersley River District. Holotype. X$\frac{4}{3}$.
Fig. 17.—**T. subglabra,** sp. nov. Hamersley River District. Holotype. Circ. nat size.
Fig. 18.—**T. subglabra,** sp. nov. Hamersley River District. Paratype. Circ. nat size.

PLATE X.

Fig. 19.—**Thamnospongia subglabra,** sp nov. Hamersley River District. Tectotype. X5.
Fig 20.—**Ragadinia placentiformis,** sp. nov. Hamersley River District. Holotype. Nat. size.
Fig. 21.—**Platychonia tertiaria,** sp. nov. Hamersley River District. Holotype. X$\frac{4}{3}$.

PLATE XI.

Fig. 22.—**Verruculina albanyensis,** sp. nov. One mile from Warriup Homestead, Albany. Holotype. X$\frac{4}{3}$.
Fig. 23.—**Dactylocalyx simpsoni,** sp. nov. Albany. Holotype. X2.
Fig. 24.—**Hemicardium,** sp. Cape Riche. X$\frac{7}{5}$.
Fig. 25.—**Cardium arcaeformis,** sp. nov. Albany. Mould. Holotype. Nat. size.
Fig. 26.—**C. arcaeformis,** sp. nov. Cast. Nat. size.
Fig. 27.—**C. arcaeformis,** sp. nov. Squeeze in plasticine. X$\frac{3}{2}$.
Fig. 28.—**Cellana jutsoni,** sp. nov. Albany. Holotype. X$\frac{4}{3}$.
Fig. 29.—**Mathilda pagoda,** sp. nov. Aldinga Bay, S. Aust. Holotype. X$\frac{3}{2}$.
Fig. 30.—**M. pagoda,** sp. nov. Aldinga. Paratype. X$\frac{3}{2}$.
Fig. 31.—**Potamides nullarboricum,** sp. nov. Aldinga, S. Aust. Holotype. X$\frac{4}{3}$.
Fig. 32.—**P. nullarboricum,** sp. nov. Aldinga, S. Aust. Paratype. X$\frac{3}{2}$.
Fig. 33.—**P. nullarboricum** sp. nov. Cape Riche. Mould. Paratype. Circ.nat size.

PLATE VI.

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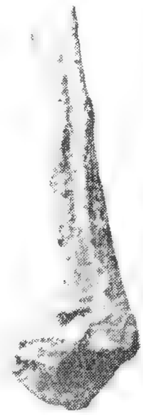

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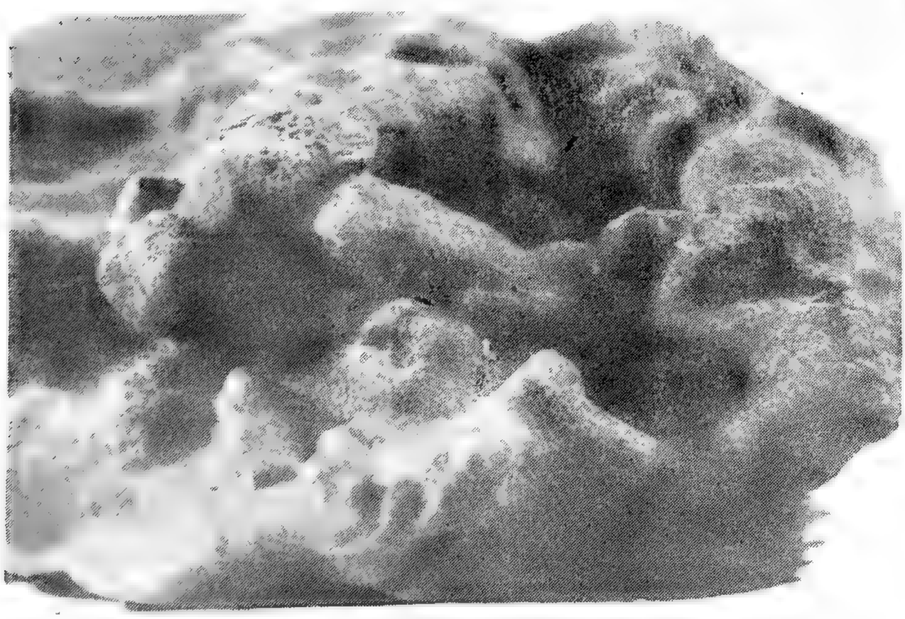

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F.C., Photo.

PLATE VII.

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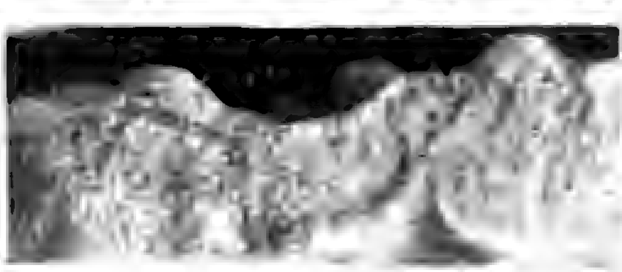

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PLATE VIII.

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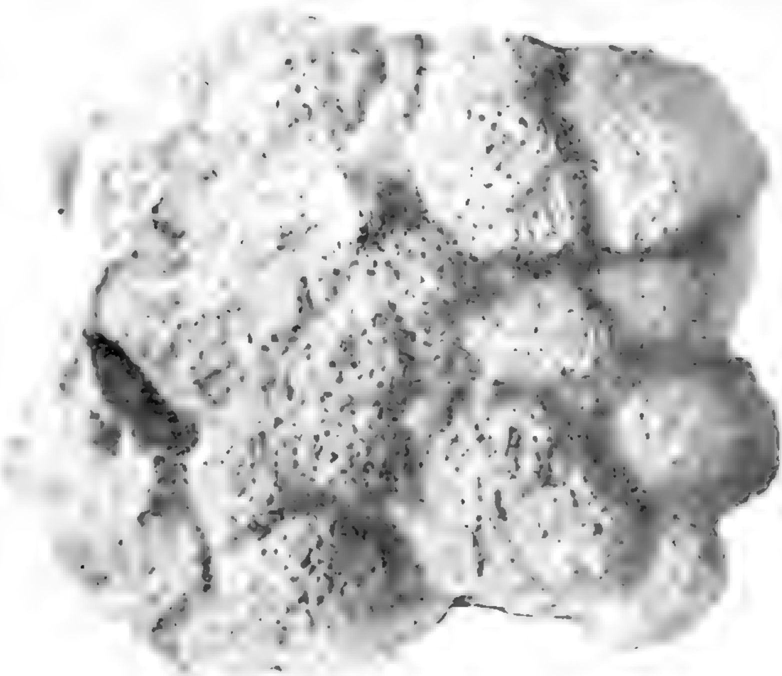

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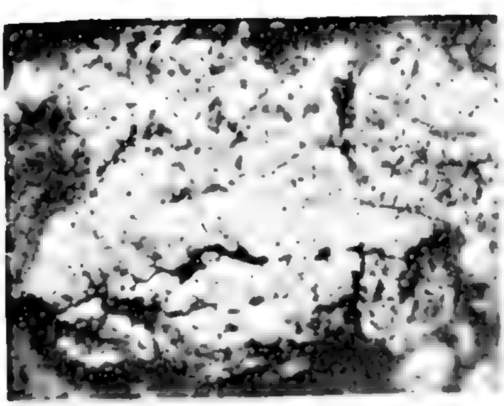

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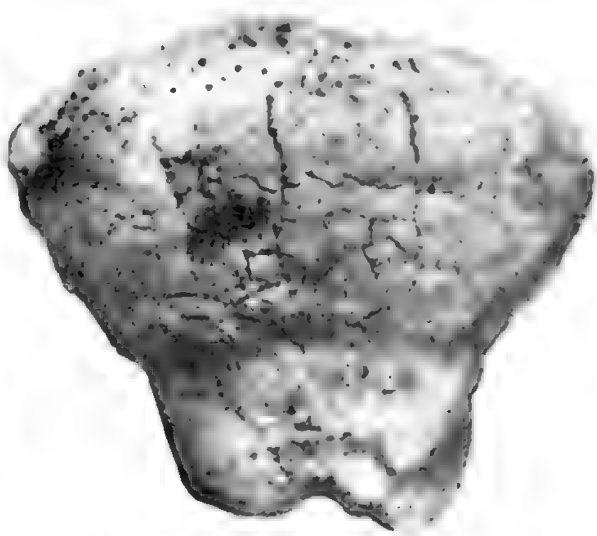

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PLATE IX.

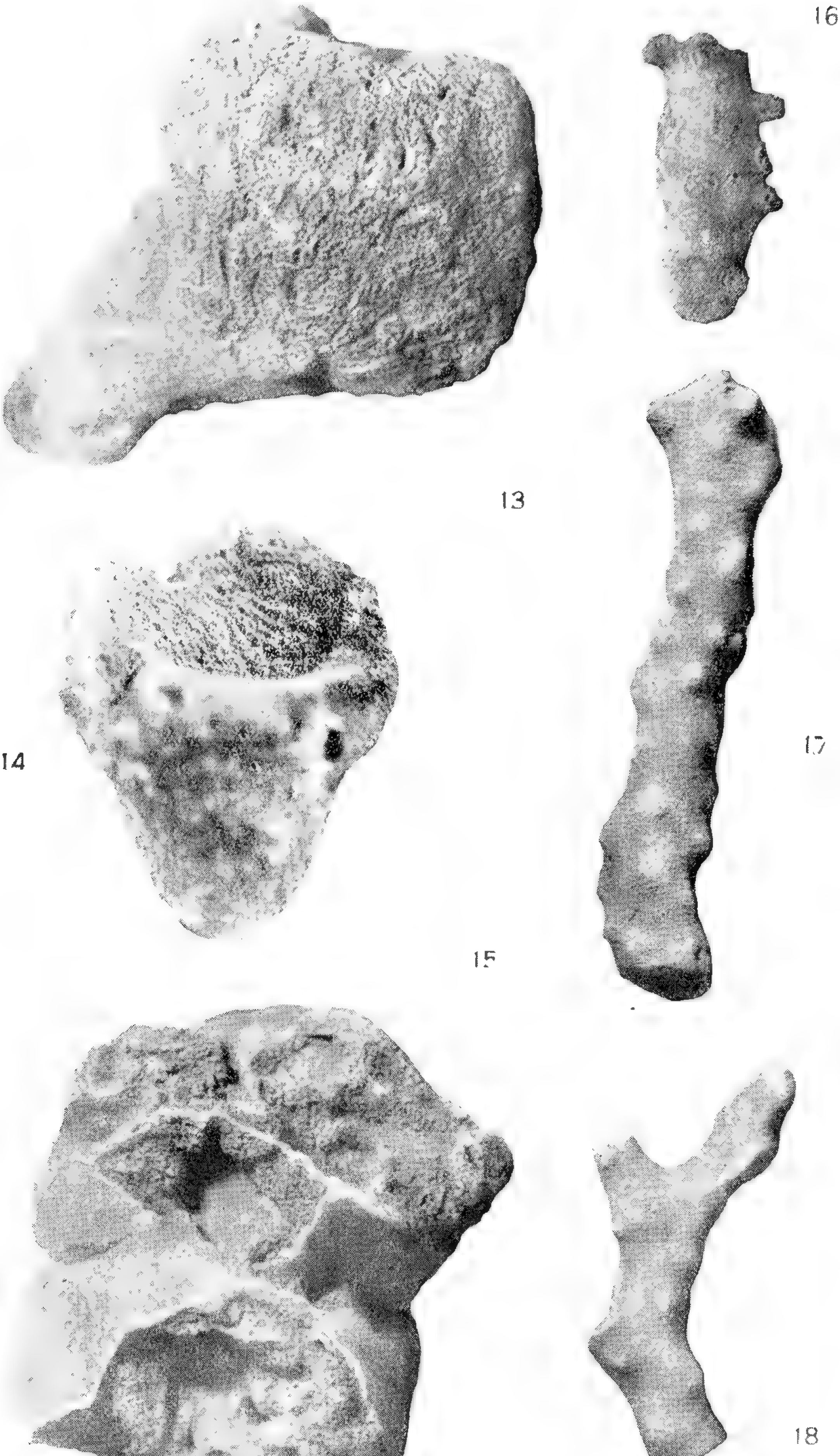

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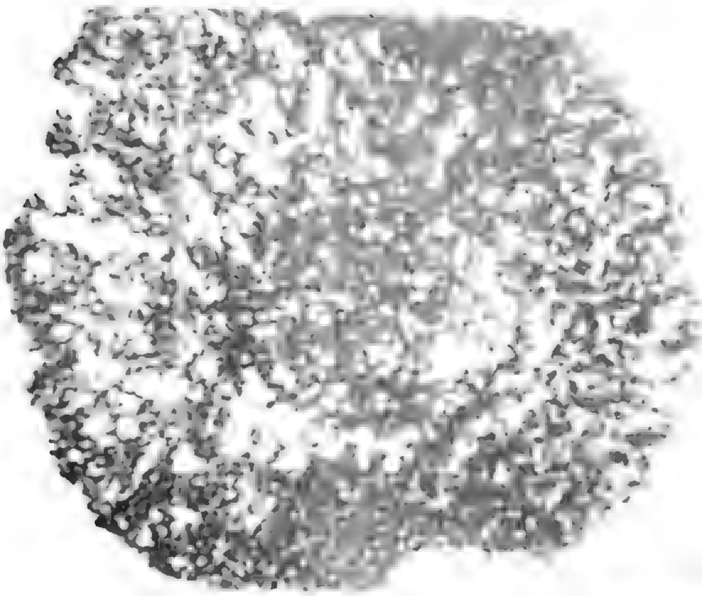
PLATE X



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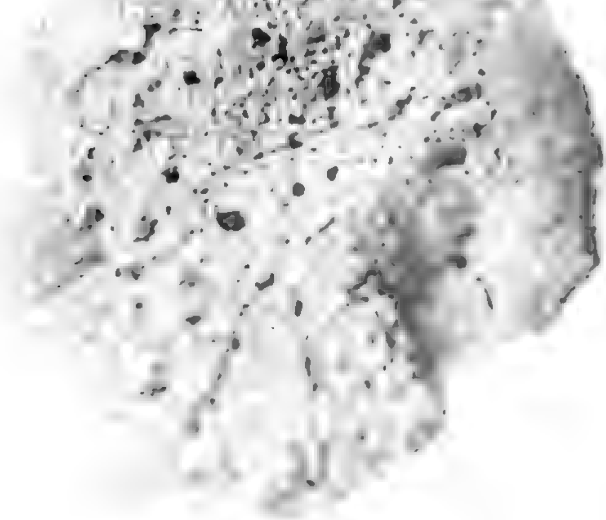

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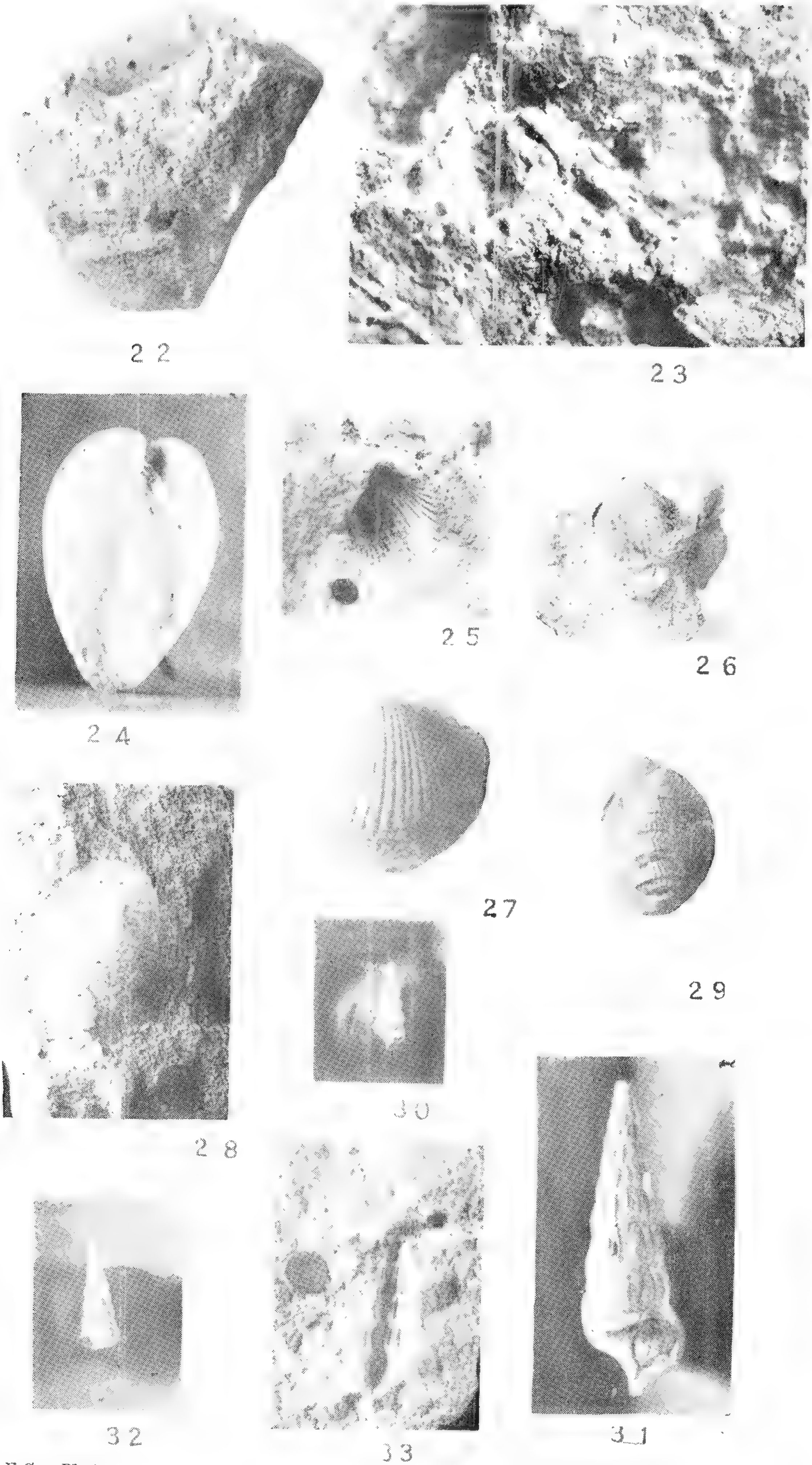
F.C., Photo.

PLATE XI.



F.C., *Photo.*

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7.—CONTRIBUTIONS TO THE FAUNA OF ROTTNEST ISLAND WESTERN AUSTRALIA.

No. IX.—THE ANTS.

BY

WILLIAM MORTON WHEELER.

Read 10th May, 1934. Published 5th October, 1934.

Communicated by L. Glauert.

INTRODUCTION.

From the twenty-first to the twenty-fifth of October, 1931, Dr. P. J. Darlington, Dr. Ira Dixson and myself, as members of the Harvard Expedition to Australia, were able to study the insect fauna of Rottnest Island through the courtesy of Mr. J. F. Allen, chairman of its Board of Control, and Mr. L. Glauert, Curator of the Museum of Western Australia. These gentlemen not only provided every comfort for our sojourn on the island but gave us facilities for visiting many parts of it. The following pages are devoted to an account of the Formicidæ which we secured and of additional collections made by Mr. Glauert since our return to the United States.

For several years Mr. Glauert has been intensively studying the ecological conditions and fauna, both terrestrial and marine, of Rottnest. I cannot do better, therefore, than quote the general topographical description with which he introduces his first contribution to the fauna of the island.[1]

"Rottnest Island lies about 12 miles westerly of Fremantle, the port at the mouth of the Swan River, and is the first glimpse of Australia obtained by vessels approaching the Continent from South Africa and Ceylon. The island, which forms the northern extremity of two submerged ridges, the Five Fathom Bank, and that of which Garden Island and Carnac are elevated portions, is rather limited in extent. It measures less than seven miles from east to west and has a maximum north to south diameter of about $3\frac{3}{4}$ miles. The surface of the island is irregular, the highest point, Lighthouse Hill, 154 feet, is situated close to the centre of the island and overlooks much low-lying land to the north and east, including the numerous and extensive Salt Lakes, which in the winter time present most charming expanses of water whose place is taken by glistening stretches of snow-white salt in the later summer months, the area of the water being considerably reduced.

"In the main, the land rises towards the north and west, where the 'coastal limestone series' of which it is composed, has weathered to form rugged cliffs and prominet headlands separated here and there by smooth, sandy beaches which vary with the season. The sand from these beaches is blown inland by the winds and has given rise to sandhills which fortunately are

[1] Contributions to the Fauna of Rottnest Island. No. 1. Introduction and Vertebrates. Journ. Roy. Soc. W. Austr. 15, 1929, pp. 37-46, map.

more or less anchored by the established vegetation. On the adjacent mainland this encroachment is slowly but surely advancing in spite of the efforts made to control it, and we may assume that the same is occurring upon Rottnest. At the 'west end' some of these sandy patches are tunnelled like a rabbit warren owing to the activities of the Petrels that have selected this part of the island as the site of a breeding colony.

"The surface soil is generally white and rich in lime and to it is added a certain amount of humus in sheltered corners in the hollows, and particularly near the few small freshwater swamps to be found here and there on the island. On the the flats between the hills in the north-eastern quadrant marly soil with *Coxiella* is either exposed on the surface or covered with a thin layer of sand. The rich animal life in the lakelets and pools of this area contrasts very markedly with that of the salt lakes whose fauna seems to be limited to the larvæ of a dipterous insect (*? Ephydra* sp.), Phyllopods (*Artemia salina*) and the Oniscids *Haloniscus* and *Deto*.

"Much of the island is clothed with dense wattle scrub tangled with creepers and undergrowth and traversed in all directions by the runs of *Setonyx brachyurus* [the quokka, or Rottnest Island wallaby] and by the tracks opened up to facilitate the passage of visitors from place to place or to provide the firewood used in the settlement during the summer season."

Fortunately, through the efforts of Mr. Allen and other citizens, Rottnest Island has been made a wild life reservation. It would probably be difficult to find in Australia a more promising site for the establishment of a laboratory for the investigation of marine, lacustrine and terrestrial organisms. The wealth of the insect fauna is indicated by the number and variety of the Formicidæ. Of the 48 different forms, representing 22 genera, recorded in this paper, 42 have been taken on the island, an increase of 33 over Clark's list published in 1929.[1] Of course, many of the mainland forms are absent from the island fauna. Conspicuous examples of these absentees are the large species of Myrmecia, or bull-dog ants, and *Aphaenogaster* (*Nystalomyrma*) *barbigula* Wheeler, which is very common along the West Australian coast, where it occupies much the same ecological environment as *A.* (*N.*) *longiceps* F. Smith in New South Wales and Queensland. Of the 17 new forms (11 species, 3 subspecies, 3 varieties) which are described, 8 species and a variety are known only from the island. To these *Rhytidoponera punctata* var. *levior* should be added, since it has not been taken on the mainland. The endemicity of several or all of these forms, however, is doubtful, both because the island is so near the mainland and because our knowledge of the West Australian ant fauna is still very imperfect, notwithstanding Forel's work, based on the extensive collections of the Hamburg Expedition of 1905,[2] and the numerous contributions of J. Clark and W. C. Crawley within more recent years. The large collection of Formicidæ amassed by the Harvard Expedition of 1931-32 shows that the West Australian fauna is much richer than had been supposed. When this material has been carefully studied and the local entomologists have collected ants more intensively and extensively, especially in such very promising regions as the Darling Range and the north-western and south-western corners of the State, the myrmecologist should have something of interest to contribute toward the solution

[1] Contributions to the Fauna of Rottnest Island. No. 3. The Ants. Journ. Roy. Soc. W. Austr. 15, 1929, pp. 55-56.

[2] *Forel, A.* Formicidae, in Michaelsen and Hartmeyer, Ergebnisse der Hamburger südwestaustralischen Forschungsreise, 1905, 1907, pp. 264-310.

of the important biogeographical problems discussed by Prof. G. E. Nicholls in his recent paper on the composition and relations of what he calls the "Hesperonotian Region" of West Australia.[1]

FAMILY FORMICIDÆ.

SUBFAMILY PONERINÆ.

Myrmecia infima Forel.

Several workers swept from flowers by Dr. Darlington and myself near Government House (X. 21, '31, and X. 22, '31) and White Hill (X. 23, '31). According to Clark, who records this diminutive bull-dog ant from Rottnest Island, it occurs along the West Australian coast from Geraldton to Albany. I have taken it at Geraldton, in King's Park, Perth, and at Margaret River, always on flowers or foliage, but have never been able to find its nest.

Rhytidoponera punctata F. Smith.

var. *levior* Crawley.

Numerous workers from a few large crater nests near the Tourist Camp Reserve at the eastern end of the island (Wheeler, X. 22, '31) and at the extreme western and near Cape Vlaming (Darlington, X. 23, '31). Rottnest Island is the type-locality of this variety, which is unknown from the mainland.

Rhytidoponera convexa F. Smith.

subsp. *violacea* Forel var. *gemma* Forel.

Several workers from a flourishing colony nesting in a rough crater near Government House (X. 22, '31), and one taken by Mr. Glauert X. 13, '32). These have the head and thorax dull purple and the postpetiole and gaster, bright metallic green. The variety is common about Perth, where it nests even in the city streets. Among several series taken in this and other West Australian localities as far south as Bridgetown, I find considerable variation in the brilliancy and coloration of the postpetiole and gaster, these parts being in some specimens purple as in the typical *violaceum,* in others dull green or even black. Perhaps the var. *gemma* is not worth recognizing.

Chalcoponera metallica F. Smith.

var. **carbonaria** var. nov.

Worker. Length 4.3 — 5 mm.

Closely related to the var. *inornata* Crawley, of about the same size and also without any traces of metallic reflections, but differing in colour and sculpture, being very dark brown or coal black, with the mandibles, trochanters, tips of coxæ, extreme bases of femora, terminal tarsal joints, gastric incisures and sting reddish yellow. Head posteriorly as in Emery's var. *cristulata*, with a more or less distinct transverse crista at the posterior border, the occipital surface rather flat and the posterior corners but slightly produced. The rugose sculpture of the thorax and petiole is distinctly finer, but the arcuate striæ interspersed with punctures on the post-petiole are decidedly coarser as are also the arcuate striæ on the first gastric segment, so that the surface is less shining.

[1] The Composition and Biogeographical Relations of the Fauna of Western Australia. Rep. Austr. and New Zealand Ass. Adv. Sci. 21, 1933, pp. 93-138.

Described from numerous specimens which I collected near White Hill (X. 23, '31) and Tourists' Camp Reserve (X. 24, '31), and one taken by Mr. Glauert near the west end of the island. They have been compared with a couple of cotypes of the var. *inornata* received from Mr. John Clark. I have taken a very similar but somewhat larger variety at Margaret River and Pemberton, Western Australia, with even coarser striæ on the first gastric segment.

Acanthoponera occidentalis Clark.

Two workers taken by Dr. Darlington near White Hill (X. 23, '31). The species was originally described from the National Park, in the Darling Range. Clark describes the abdomen as having a yellow tinge, but the coloration of this region is inconstant. One of the Rottnest specimens has the postpetiole and first gastric segment very dark brown, except along their posterior borders. Six specimens, which I found under a large, rather deeply imbedded stone in the type-locality, have these parts as dark as, or in a few cases darker, than the thorax and one of three specimens, which I took at Margaret River has the postpetiole and first gastric segment as dark as in the Rottnest specimen. *A. occidentalis* is hypogaeic in habit like *Brachyponera lutea* and the Australian species of **Amblyopone.**

Euponera (*Brachyponera*) *lutea* Mayr.

Workers and a deälated female taken near White Hill (Wheeler, X. 23, '31), workers taken by Darlington near Cape Vlaming (X. 23, '31), and by Mr. Glauert at City of York Bay (XII. 13, '32). This is a common species distributed throughout Australia.

Euponera (Trachymesopus) clarki sp. nov.

Worker. Length 4.5 — 5 mm.

Head subquadrate, without the mandibles; only slightly longer than broad, nearly as broad in front as behind, with straight posterior border and nearly straight, sub-parallel and somewhat dorsoventrally compressed sides. Eyes small, situated at the anterior third of the sides, half as long as their distance from the clypeal border, feebly convex. Mandibles with distinctly concave external borders, 10-toothed, the five apical teeth larger, especially the first, second, third and fifth, the five basil teeth small, subequal and blunt. Clypeus very short and transverse, thick and welt-like at the sides, carinate in the middle posteriorly, its anterior border broadly and feebly bisinuate. Frontal carinæ with sub-triangular, very closely approximated, almost fused lobes, slightly turned upward laterally, continued for a short distance as delicate posteriorly diverging ridges; frontal groove indistinct, very short, not reaching the middle of the head. Antennæ stout, scapes attaining the posterior corners; funicular joints 1 and 2 subequal, nearly twice, joints 3-7 one and one-half times as long as broad; 8-10 slightly broader than long; terminal joint pointed, less than twice as long as the two preceding joints together. Thorax scarcely longer than the head, plus the mandibles, with distinct promesonotal and feeble or even subobsolete mesoëpinotal sutures; in profile evenly arcuate above, the outline slightly interrupted at the sutures, the base and declivity of the epinotum subequal, rounding into each other so that in some specimens the two surfaces form an even, sloping convexity; pronotum from above twice as broad as long, semicircularly rounded in front, the mesonotum broadly, transversely subelliptical, the

epinotum nearly one and one-half times as long as broad, the declivity triangular, acutely pointed above and crenulately marginate on the sides. Petiole from above more than twice as broad as long, arcuate in front, straight behind; the scale circular from behind, in profile fully twice as high as long and as high as the epinotum, narrowed above, with distinctly concave anterior and straight superior and posterior faces; ventrally with an elongate but not very deep appendage, which is straight below, obliquely truncated anteriorly and bluntly bidentate posteriorly. Pospetiole and gaster somewhat broader than long, the former sharply, perpendicularly truncated anteriorly. Sting well-developed. Legs rather stout; median tibiæ short and clavate.

Head, thorax, legs and antennæ subopaque, mandibles finely striated and coarsely and sparsely punctate; head and thorax densely and evenly punctate, the cavities of the punctures shining and microscopically striolate; clypeus sparsely punctate; cheeks finely, sides of thorax more coarsely, longitudinally rugulose; declivity of epinotum, anterior and posterior surfaces of petiolar scale smooth and very finely and indistinctly punctulate; post-petiole and first gastric segment punctate like the thorax but more sparsely; remainder of gastric segments transversely shagreened; scapes and legs densely punctulate.

Hairs and pubescence whitish, the former short, erect, rather abundant on the head and thorax, longer on the gula, fore coxæ and abdomen; the pubescence dense and fine but not concealing the integument, appressed, longer on the body than on the appendages. Middle tibiæ with a number of short, stiff bristles on their extensor surfaces as in other species of Trachymesopus.

Black; mandibles, frontal carinæ, antennæ, legs and more or less of the medium and hind coxæ, sting and posterior borders of postpetiolar and gastric segments brownish red; median portions of scapes and femora somewhat infuscated.

Female (deälated). Length 5.5 mm.

Very similar to the worker, with the usual caste differences; eyes larger, as long as their distance from the clypeus; ocelli rather widely separated; mesonotum larger, one and one-half times as broad as long, semi-circular anteriorly, epinotum with distinct base and declivity, the former horizontal and only one-fifth as long as the latter, which is straight and rather steep. Petiolar scale more compressed anteroposteriorly than in the worker, its superior border indistinctly and bluntly pointed in the middle. Abdomen more voluminous, with longer and more abundant pilosity.

Described from six workers taken near Serpentine Lake, Rottnest Island (X.23.'31) from a small colony nesting under a stone and a female of the same species taken with a few workers at Margaret River, W.A. The species is dedicated to Mr. John Clark who sent me female and worker specimens from Armadale, W.A.

This is the first Trachymesopus to be described from West Australia. It is very different from *darwini* Forel from Queensland, India and Africa, *rotundiceps* Emery of New Caledonia, and *crassinodis* Clark from Victoria, which was referred with some doubt to the subgenus Trachymesopus.

Ponera congrua sp. nov.

Worker. Length 3—3.5 mm.

Head about one-fifth longer than broad, slightly broader behind than in front, with feebly concave posterior border, rounded posterior corners and feebly and evenly convex sides. Eyes minute, consisting of only four or five facets, situated one-fourth the distance from the clypeal suture to the posterior corners. Mandibles large and broad, with straight external and masticatory borders, the latter long, with five larger, blunt, apical teeth and six or seven rather indistinct, irregular, basal denticles. Clypeus convex but not carinate in the middle, its sides depressed, its anterior border broadly rounded and but slightly advanced in the middle. Frontal carinæ small, rounded, closely approximated and ciliate; frontal groove distinct, extending well behind the middle of the head. Antennæ rather long; scapes reaching the posterior corners, rather slender at the base, enlarged distally; funiculi without distinct club; their first joint slightly more than twice as long as broad, second as long as broad, the succeeding joints, especially 3-6 distinctly shorter than broad, the terminal joint pointed, not longer than the two preceding subequal joints together. Thorax with distinct, arcuate and impressed promesonotal suture, the mesoëpinotal suture indistinct or obsolete; posterior portion of pronotum, the mesonotum and base of epinotum in profile nearly straight and horizontal, the epinotal declivity elliptical from behind, narrowed above, as long as the base, straight and sloping, marginate on the sides. Pronotum, without the neck, from above nearly twice as broad as long, broadly rounded in front and broader than the mesonotum which is transversely elliptical and twice as broad as long; epinotum narrower, somewhat longer than broad, parallel-sided and laterally compressed dorsally. Petiole in profile twice as high as long, and as high as the epinotum, its ventral appendage small, elongate, trapezoidal; scale in profile distinctly narrowed dorsally, with straight anterior, superior and posterior surfaces; from above slightly broader than the epinotum, somewhat more than twice as broad as long, broadly arcuate anteriorly and straight posteriorly; from behind nearly circular. Postpetiole and first gastric segment broader than long, the former perpendicularly truncated in front. Legs rather slender.

Shining; dorsal surface of head more opaque. Mandibles smooth, with fine scattered punctures; clypeus and head evenly and densely, remainder of body and legs more finely and more sparsely punctate; antennal scapes subopaque, densely punctulate.

Pilosity and pubescence pale yellowish; the former rather short, erect and abundant, especially on the gaster and thoracic dorsum, the pubescence dense and somewhat oblique, best developed on the head and gaster where it partially conceals the shining integument, very fine on the appendages.

Yellowish red; legs, antennæ and tip of gaster paler, yellow; the head above, the epinotum, postpetiole and gaster in some specimens darker and more brownish.

Female **(deälated). Length 4-4.2 mm.**

Differing from the worker in colour and pilosity, the head, postpetiole, and first and second gastric segments being dark brown or blackish, their posterior borders, the thorax and petiole reddish brown or castaneous, the mandibles, antennæ and legs testaceous. Body more opaque than in the worker owing to the longer pubescence; erect hairs, especially on the gaster, epinotum and petiolar scale longer and more abundant. Eyes much larger,

rather convex, nearly as long as their distance from the anterior corners of the head. Frontal groove reaching to the anterior ocellus. Both pro- and mesonotum broader than in the worker, epinotum with feebly convex base, half as long as the straight, sloping declivity. Petiolar scale more compressed above than in the worker, from behind more oval, with the sides less convex and more convergent ventrally. Gaster more voluminous.

Described from 16 workers and 8 females taken by Dr. Darlington and myself near White Hill, nesting in sandy soil covered by the lower branches of some small Malvaceous shrubs (X.23.'31). Mr. Glauert has also contributed a worker from the island (XII.'31). This, the first species of Ponera to be described from West Australia, seems to be sufficiently distinct from certain closely allied but as yet undescribed forms which I have taken on the mainland (Margaret River, Pemberton, Geraldton, etc.) and in other parts of Australia.

Leptogenys (*Lobopelta*) *neutralis* Forel.

A single colony of this very active, jet black ant was taken by myself under a log at the edge of a small pond near Mud Lake (X.23.'31). It is certainly rare on the island and in the vicinity of Perth, but very common at Pemberton and Margaret River. I have figured and discussed it at length in my book "Colony Founding among Ants," Harvard Univ. Press. 1933, pp. 85-90, Fig. 27. Since the female is apterous and ergatomorphic we must suppose this this species existed on the Island before its separation from the mainland. The same is true of the two species of Rhytidoponera cited above, which possess no female caste distinguishable from the worker.

SUBFAMILY MYRMICINÆ.

Pheidole hartmeyeri Forel.

Mr. Clark states that several specimens of this species, originally described from Fremantle, were taken by Mr. Glauert on Rottnest Island. We did not succeed in finding it during our visit to the island, probably because it is a rather rare or local insect.

Pheidole ampla Forel.

Numerous soldiers and workers taken by myself in the vicinity of Government House (X. 21, '31), White Hill (X. 23, '31), Longreach Bay (X. 24, '31) and Nancy Cove (X. 25, '31) and by Mr. Glauert near Lake Herschel (III. 27, '32). All were nesting under stones in open grassy places. The colonies are small or of medium size. Mr. Glauert found that this ant is a true harvester and stores its seeds in the superficial chambers of the nest.

All the Rottnest specimens belong to the typical form of *ampla*, which was described from specimens taken by Walker on the Abrolhos (E. Wallaby Island). Mr. W. E. Schevill, while collecting on West Wallaby Island (X. 24, '31), secured for me a series of topotype soldiers and workers so that I am certain of my identification of the Rottnest material. Varieties of *ampla* (e.g. *perthensis* Crawley) occur on the adjacent mainland and others in Eastern Australia and even on Norfolk Island.

Pheidole (*Anisopheidole*) *froggatti* Forel.

A few specimens of this extraordinary ant were taken by Dr. Darlington from a small colony at Nancy Cove (X. 24, '31). It is rather rare in the vicinity of Perth but I found many fine colonies at Margaret River. Unlike

nearly all the other species of the huge, cosmopolitan genus Pheidole, it is decidedly hypogaeic in habits, has very poorly developed eyes and an extremely polymorphic soldier caste. The colonies must be very difficult to detect during the dry season. In the moist open forests about Margaret River, however, they are easily found under large stones deeply imbedded in the soil. When fully developed the colonies comprise hundreds of individuals and thousands of subspherical larvæ, and it is only in such flourishing colonies that one encounters perfect series of soldiers showing all the transitions between huge, large-headed forms and minute, small-headed workers proper. The appearance and behaviour of this ant is so different from other species of Pheidole that I am inclined to regard Anisopheidole as an independent, exclusively Australian genus.

Crematogaster (*Acrocoelia*) *laeviceps* F. Smith var. *chasei* Forel.

I collected many workers and females of this ant near Government House (X. 22, '31, under bark of large *Callitris robusta* trees and running in files on their trunks), near White Hill (X. 23, '31, under stones), near Longreach Bay (X. 24, '31, under stones) and Serpentine Lake (X. 25, '31, on the trunks of wattles and nesting under their bark). This variety has also been taken by Mr. Glauert and was previously recorded from the island by Clark. The typical *laeviceps* was originally described from Queensland, its var. *chasei* from Perth. I append descriptions of the hitherto unknown female and of the male from specimens taken in King's Park, Perth.

Female (deälated). Length 7.5-8 mm.

Much larger than the worker, which measures only 3.2-3.7 mm. Head subquadrate, very nearly as long as broad, with straight, subparallel sides, feebly concave posterior border and broadly rounded posterior corners. Eyes feebly convex, as long as their distance from the anterior corners. Antennal scapes reaching slightly beyond the posterior orbits. Thorax elongate-elliptical, somewhat more than twice as long as broad; mesonotum distinctly longer than broad, epinotum with very short, convex base, about one-fourth as long as the abrupt, slightly concave declivity, quite unarmed or with only minute angles representing the spines of the worker epinotum. Gaster long and voluminous, parallel-sided, acuminate at the tip. Sculpture, pilosity and coloration as in the worker, but the front and sides of the head more strongly striated or longitudinally regulose as far back as the level of the posterior orbits.

Male. Length 3-3.2 mm.

Head very small, though the eyes nearly one and one-half times as broad as long, with convex and broadly rounded postocular portion and very short cheeks. Mandibles small, narrow, with acute, obscurely tridenticulate masticatory borders. Clypeus short, convex in the middle, its anterior border straight and transverse. Antennal scapes more slender than the funiculus, cylindrical, one and one-half times as long as broad; funiculi 11-12-jointed; first joint not globular, broader than long, second and third more or less completely fused to form a single joint; fourth as long as broad, remaining joints longer. Thorax short and high; mesonotum very convex in front where it overhangs the neck; scutellum large and protuberant; epinotum small, with subequal base and declivity and indications of a pair of small, broad denticles or angles, the base convex, the declivity abrupt and somewhat concave. Petiole and postpetiole short, their nodes subequal, broad and compactly united, the node of the postpetiole emarginate behind. Legs slender, hind femora bowed. Wings rather broad.

Sculpture and pilosity as in the worker but head subopaque, punctate-rugulose and mesonotum with coarse, scattered, piligerous punctures. Black; mandibles, appendages, thoracic sutures, posterior borders of gastric segments and genitalia piceous; femora infuscated in the middle. Wings white, with white veins and pale brown pterostigma.

Crematogaster (*Orthocrema*) *dispar* Forel.

A few workers and a deälated female taken by myself near Lady Edeline Beach (X.23.'31). This hypogæic ant is very common on the mainland in the vicinity of Margaret River, Pemberton and Augusta, where it forms populous colonies under stones deeply imbedded in the soil. The brown females measure 7-8 mm. and are very large compared with the yellow workers, which are only 2-2.5 mm. in length. The female larvæ are nearly spherical.

Monomorium (Notomyrmex) insolescens sp. nov.

Worker. Length 2.5-3 mm.

Head subrectangular, slightly longer than broad and scarcely broader in front than behind, with feebly convex sides and concave posterior border. Eyes rather large, moderately convex, situated about their own length from the anterior corners of the head. Mandibles broad, their masticatory borders with five regular teeth, their external borders rather straight. Clypeus very short, strongly bicarinate, the carinæ projecting anteriorly as two stout teeth, separated by a deep concavity. Frontal carinæ flattened, horizontal, slightly lobulate behind the antennal insertions; frontal area small, indistinct, impressed; frontal furrow obsolete. Antennæ 12-jointed, scapes reaching to about twice their greatest diameter from the posterior corners of the head; joints 2-7 of the funiculi a little broader than long; eighth joint as long as broad; club 3-jointed, its two basal joints subequal and together as long as the terminal joint. Thorax stout, about twice as long as broad, and nearly as broad as the head through the humeri, which are rounded, both the pro-mesonotal and the mesoëpinatol sutures absent. Mesonotum and epinotum laterally compressed. In profile the thorax is convex in front, the dorsal outline straight, without mesoëpinotal impression or constriction, sloping slightly at the base of the epinotum which is feebly angular in the middle in profile, longer than the declivity, which bears at its middle on each side a blunt denticle continued down as a ridge to the well-developed, translucent metasternal angle. Petiole and postpetiole stout, the peduncle of the former very short, the node subcuboidal, a little higher than long, with perpendicular anterior and posterior surfaces and horizontal summit; from above broader than long, rounded in front and straight behind. Postpetiole with a prominent acute tooth at its anteroventral end, the node somewhat lower than that of the petiole, also subcuboidal in profile, as long as high, rectangular from above, distinctly broader than long and broader than the petiolar note. Gaster small, lenticular, scarcely longer than broad, convex above, with concave anterior border. Legs rather stout.

Shining; mandibles smooth, sparsely punctate; head covered with scattered, piligerous punctures, cheeks and front longitudinally rugulose; thorax, petiole and postpetiole subopaque, densely and finely punctate, except the upper surface of the pronotum which is smooth and shining; meso- and metapleuræ vaguely, longitudinally rugulose. Gaster and legs smooth and shining; sparsely punctate.

Hairs yellow, sparse, erect, moderately long on the body, shorter and more numerous on the legs and scapes.

Red; pedicel and posterior portion of thorax darker; head and antennæ paler; gaster and legs, including coxæ, yellow.

Male. Length 2.5 mm.

Heading including the eyes about as long as broad; broadly convex behind; eyes and ocelli very large, cheeks very short; mandibles small, 5-toothed; clypeus convex in the middle, with evenly rounded anterior border; frontal carinæ short but distinct. Antennal scapes four times as long as broad, cylindrical, somewhat curved, first funicular joint as long as broad, not globose, the remaining joints longer but not narrowing distally. Thorax small and short, not broader than the head. Mesonotum convex, overarching the pronotum in front, without notauli (Mayrian furrows); scutellum rather small, not prominent. Epinotum sloping, without distinct base and declivity. Petiolar and postpetiolar nodes similar to those of the worker but smaller, lower and more rounded. Gaster small; genitalia prominent, the stipites thin, broad, rounded and incurved. Legs moderately slender. Wings with well-developed veins and pterostigma, with a discoidal and one cubital cell and the marginal cell open at the apex.

Mandibles shining, sparsely punctate; head opaque, densely and finely punctate; thoracic sculpture much as in the worker, but the sides of the epinotum and pedicel loosely, longitudinally rugulose.

Hairs shorter than in the worker and more abundant on the thorax and appendages.

Black; gaster, thoracic sutures and legs piceous; wings greyish hyaline, with pale brown veins and pterostigma.

Described from six workers and two males taken by W. D. Dodd at Derby, West Australia.

This species is very aberrant in the structure of the thorax and pedicel of the worker and small size of the male, so that its position in the subgenus Notomyrmex is somewhat doubtful. It is described here because the following species from Rottnest Island and Ludlow, West Australia, is very similar.

Monomorium (Notomyrmex) longiceps sp. nov.

Worker. Length 2.3-2.8 mm.

Averaging slightly smaller than *insolescens* and differing in the following characters: Head trapezoidal, longer, narrower and more distinctly broader in front than behind, with straight sides; eyes smaller and nearer the middle of the sides; mandibles narrower, 4-toothed; antennal scapes shorter as are also joints 2-8 of the funiculus. Epinotum in profile rectangular, the declivity perpendicular, with the denticles larger and continued as crenulated ridges to the metasternal angles, which are small and poorly developed. Peduncle of petiole longer, more sharply marked off from the node. This and the postpetiole are of the same width but much more rounded and less cuboidal than in *insolescens*; petiolar node from above as long as broad, rather narrowly rounded in front, contracted behind; postpetiole subtrapezoidal, one and one-third times as broad as long, broader in front than behind, with rounded corners and short, straight, posteriorly converging sides.

Sculpture of the head similar to that of *insolescens*, but the longitudinal rugules are continued back beyond its middle and the sparse punctures on its posterior portion are coarser. Mandibles rather coarsely striate-punctate.

Thorax longitudinally rugulose throughout, except the declivity of the epinotum which is transversely striate; dorsal portion of pronotum more loosely rugose and therefore more shining than the remainder of the thorax. Petiolar node above arcuately rugulose; postpetiole with a few short, longitudinal sulci. Gaster smooth and shining, with very sparsely, piligerous punctures.

Pilosity somewhat more abundant than in *insolescens*.

Colour of the head and thorax the same, but the gaster is also red and not yellow and the antennæ and legs are brownish red, darker than the head and thorax, the tarsi paler.

Described from a single specimen which I found running on the ground near Lady Edeline Beach (X.23.'31), and two workers from Ludlow, Western Australia, received from Mr. John Clark.

Meranoplus ferrugineus Crawley.

Two deälated females taken by Dr. Darlington at Longreach Bay (X.24.'31) are doubtfully referable to this species. The female of *ferrugineus* has not been described and there are in my collection several closely allied, small, ferruginous, West Australian Meranopli, which have not been described.

Xiphomyrmex viehmeyeri Forel.

var. **venustus** var. nov.

Female (deälated). Length nearly 4 mm.

Differing from the female of the typical *viehmeyeri* in coloration, the head, thorax, pedicel and antennæ being red, the clypeus, front and gaster castaneous, the mandibles and legs reddish yellow, the mandibular teeth, ocellar triangle, wing-insertions and scutellum black.

A single specimen which I found under a stone near Government House (X.22.'31). I have taken the female of the typical *viehmeyeri* with workers at Meekatharra, Western Australia. In both phases, the head, thorax and pedicel are rich, reddish brown, the gaster yellow.

SUBFAMILY DOLICHODERINÆ.

Dolichoderus (*Hypoclinea*) *clusor* Forel.

Numerous workers taken by Dr. Darlington, Dr. Dixson and myself near Government House (X.22.'31) and at Longreach Bay (X.24.'31). In the former locality they were nesting in a mass of dead, compressed grass under a stone. The type-locality of the species is Fremantle.

Dolichoderus (Hypoclinea) glauerti sp. nov.

Worker. Length 3-3.5 mm.

Head oval, one-fifth longer than broad, rounded behind and strongly narrowed in front, with feebly convex sides; eyes large, convex, at the middle of the sides. Mandibles stout and convex, with straight external borders; masticatory borders with two larger apical teeth and an even series of about 10 basal denticles. Clypeus moderately convex but not carinate in the middle, its anterior border with a deep, broad median emargination and impression. Frontal area distinct, triangular. Frontal carinæ subparallel anteriorly, diverging posteriorly and terminating at the level of the middle of the eyes. Antennæ slender; scapes extending somewhat more than one-fourth their length beyond the posterior border of the head; first and third

long, the base convex anteriorly, somewhat sloping and passing into the longer, perpendicular declivity through a rounded angle. Mesonotum from above subhexagonal, as broad as long; scutellum nearly as long as broad. Petiole with a low, thick, subcuboidal node, which is nearly twice as broad as long and somewhat narrower in front than behind. Gaster rather slender; stipites of genitalia triangular, slightly longer than broad, acuminate; volsellæ small, cultrate. Legs slender.

Subopaque; gaster shining; head, thorax, petiole and legs finely and sharply reticulate, the head more coarsely; gaster finely shagreened as in the worker. Scutellum with three small pit-like impressions on each side.

Erect hairs shorter and less numerous than in the worker, absent on the gaster, except at its tip. Pubescence present on appendages and gaster, yellowish, rather long and appressed, but dilute.

Black; incisures of gaster and terminal tarsal joints pale piceous; wings white, with brownish veins and dark brown pterostigma.

Described from 16 workers and 6 males taken by Mr. Glauert at City of York Bay, Rottnest Island, Dec. 13, 1932.

This interesting ant differs in the structure of the epinotum of the worker from all the Australian species of Dolichoderus, except *D. australis* Ernest André of Victoria. This species, however, is decidedly larger and has a very different sculpture and coloration.

Iridomyrmex darwinianus Forel.

var. *fidus* Forel.

Many workers taken under stones near Government House (X. 21, '31) and Longreach Bay (X. 24, '31). This form, originally described from Western Australia (Guildford, Bridgetown, etc.), is a slight variant of the typical *darwinianus* of New South Wales, Victoria and South Australia, which Forel regarded as the type of the subgenus Doleromyrma, of the genus Tapinoma.

Iridomyrmex rufoniger Lowne.

Recorded by Mr. John Clark from Rottnest Island. He remarks that "the examples taken by Mr. Glauert are not quite typical but are too close to separate at present." I did not succeed in finding this species on the island but instead the following two related forms:—

Iridomyrmex chasei Forel.

Numerous workers from populous colonies under stones near Government House (X. 22, '31) and Longreach Bay (X. 24, '31) and a series taken by Mr. Glauert at City of York Bay (XII. 13, '32). These specimens were compared with authentic workers taken by the Hamburg Expedition to Western Australia in 1905 at Day Dawn and received from Forel. I have found the typical *chasei* also near Perth, which is the type locality.

Iridomyrmex chasei subsp. *yalgooensis* Forel.

This form, described as a variety from Yalgoo, Geraldton, etc., deserves to rank as a subspecies owing to its uniformly smaller size, different coloration and differently shaped epinotum. It is much more abundant on the island than the typical *chasei*. I have taken workers and deälated females from populus colonies near Garden Lake (X. 21, '31), Government House (X. 21, '31), and Lady Edeline Beach (X. 23, '31).

funicular joints longer than the second, joints 4-6 about twice as long as broad, remaining joints shorter, except the last which equals the two preceding joints together. Thorax slender, from above narrower than the head, broadest through the pronotum, which is as long as wide, nonepaulate, slightly depressed, in the middle above feebly, on the sides more deeply concave; mesonotum narrower than the pronotum, elliptical, slightly broader than long, moderately convex, sloping; epinotum only half as broad as the pronotum, parallel-sided, half again as long as wide. In profile the dorsal surface of the pro- and mesonotum form a single moderate convexity; mesoëpinotal impression short and rather acute, with the metanotal spiracles at its sides; base of epinotum in profile rising rather sharply as a pronounced convexity and passing abruptly into but not over-arching the longer declivity, the superior two-thirds of which are straight and sloping, the inferior third horizontal and concave. The two surfaces are separated by a distinct, transverse margination produced as a small tooth on each side. Petiolar scale in profile high and thin, inclined forward, its anterior and posterior surfaces parallel, its superior border bevelled anteriorly and rather sharp; seen from behind the scale is nearly one and one-half times as high as broad, broad above, with rounded superior border and straight, ventrally converging sides, which merge at the base into a distinct posterior peduncle. Gaster rather voluminous, first segment with a deep impression for the accommodation of the petiolar scale.

Shining, the gaster more so than the remainder of the body. Mandibles coarsely and sparsely punctate. Sides of clypeus, cheeks and sides of front sharply and rather finely longitudinally rugulose, remainder of head finely and regularly reticulate; mesonotum and epinotum transversely rugulose, the former and the base of the latter also irregularly but not sharply foveolate so that the surface is very uneven; sides of thorax longitudinally rugulose; gaster finely, transversely shagreened, with very sparse, fine, piligerous punctures; antennal scapes and legs subopaque, very finely granular and sparsely punctate.

Pilosity greyish, erect on the body, moderately abundant and of very uneven length; short on the appendages, more abundant on the scapes than on the legs. Pubescence absent.

Mandibles, head, thorax, fore coxæ and petiole brownish red or reddish brown; petiole darker brown; gaster black, with dull whitish posterior borders to the segments; antennal scapes yellow; funiculi red; legs and middle and hind coxæ yellowish white; knees and tarsi reddish.

Male. Length 3-3.5 mm.

Head one third broader than long, with evenly rounded postocular region and prominent, widely separated ocelli; eyes large and convex, with emarginate internal orbits; cheeks straight, about one third as long as the eyes, anteriorly converging. Mandibles small, acute, with concave external and straight, minutely denticulate masticatory borders. Clypeus similar to that of the worker but the median emargination smaller; frontal carinæ distinct. Antennal scapes stout, a little more than twice as long as broad, first funicular joint slightly longer than broad, second somewhat more than three times as long as broad, remaining joints, except the last, gradually decreasing in length. Thorax short and stout, through the wing-insertions as broad as the head; pronotum and anterior end of mesonotum in profile straight and perpendicular, forming nearly a right angle with the somewhat flattened posterior portion of the mesonotum; scutellum prominent; epinotum higher than

Iridomyrmex bicknelli Emery.

var. *splendidus* Forel.

Numerous workers from crater nests in pure sand near Government House (X. 22, '31) and on Lady Edeline Beach (X. 23, '31). The movements of workers are exceedingly quick, and the colonies are much less populous than those of *chasei* and *yalgooensis*. It is also common along the beaches of the adjacent mainland.

Iridomyrmex matiroloi Emery.

var. *splendens* Forel.

Several workers from a single colony under a stone at Nancy Cove (X. 24, '31).

Iridomyrmex exsanguis Forel.

Five workers from Nancy Cove (X. 24, '31).

Iridomyrmex punctatissimus Emery.

A dozen workers taken by Mr. Glauert from a single colony at City of York Bay, Dec. 13, '32, agree perfectly with Emery's description of the types from Mt. Victoria, New South Wales, except in their distinctly smaller size. They measure only 1.3-1.5 mm., whereas Emery's measured 2-2.5 mm. Since I have taken specimens of the latter dimensions in King's Park, Perth, and possess others collected by H. H. Elston on Mt. Lofty, near Adelaide, South Australia, I hesitate to regard the Rottnest specimens as representing a distinct variety.

Tapinoma (Micromyrma) rottnestense sp. nov.

Worker. Length:

Head suboblong; about one and one-fourth times as long as broad, as broad in front as behind, with straight posterior and very feebly convex sides. Eyes larger, rather flat, longer than their distance from the anterior corners of the clypeus. Mandibles with moderately convex external and oblique masticatory borders, the latter with two larger apical and six or seven minute basal denticles. Palpi simple. Clypeus convex in middle, depressed on the sides, its anterior border distincly sinuate in the middle and on each side. Frontal carinæ short, distinctly diverging posteriorly; frontal area and groove obsolete. Antennal scapes curved at base, reaching slightly beyond the posterior border of the head; first funicular joint as long as 2 and 3 together, joints 2-10 subequal, nearly one and one-half times as long as broad. Thorax rather slender, laterally compressed behind the pronotum, which is twice as broad as long without the neck, and rounder anteriorly and laterally; mesonotum subtriangular, narrowed behind and almost submarginate on the sides, as long as broad. In profile the dorsal outline of the thorax is nearly straight and horizontal, very slightly impressed at the mesoëpinotal suture, so that the base of the epinotum continues the general outline of the thoracic dorsum but forms a distinct obtuse angle with the sloping, longer declivity; from behind the declivity is oval, submarginate on the sides and above.

Petiole small, elliptical, about twice as long as broad, in front with a vestigial, narrow, much inclined scale. Gaster of the usual form, its first segment projecting and covering the petiole.

Slightly shining, head more opaque; surface very finely punctulate; mandibles coarsely and sparsely punctate.

Hairs and pubescence white; the former present only on the mandibles, clypeus and tip of gaster; pubescence very short and fine; not sufficiently dense to conceal the integument; longest in the head, especially on the cheeks and sides.

Reddish brown; the head distinctly darker; mandibles and anterior border of clypeus reddish, the teeth of the former red; antennæ, legs and posterior borders of gastric segments pale yellowish brown; funiculi beyond the first joint and median portions of hind femora and tibiæ dark brown.

Described from four specimens which I found under a stone at Lady Edeline Beach (X. 23, '31).

This species is quite distinct from the East Australian *T. minutum* Mayr and its varieties *integrum* Forel and *cephalicum* Santschi in its longer, much more rectangular head, much larger eyes and much longer funicular joints.

SUBFAMILY FORMICINÆ.

Melophorus insularis sp. nov.

Worker major. Length 5.5 mm.

Head moderately large, subrectangular, about one-fourth broader than long without the mandibles, with straight posterior border, broadly rounded posterior corners and straight, subparallel sides. Eyes rather large and convex, their longest diameter somewhat greater than twice the greatest diameter of the antennal scapes, situated behind the middle of the sides. Mandibles convex, not geniculate at the base, with oblique 5-toothed masticatory borders, the apical tooth long, a short but distinct diastema between the third and fourth and the fourth and fifth tooth, the last turned slightly backward. Clypeus convex and subcarinate in the middle, its anterior border produced and very feebly and narrowly sinuate in the middle. Frontal area very distinct, triangular; frontal groove short, reaching only halfway to the anterior ocellus. Antennal scapes extending fully one-fourth their length beyond the posterior border of the head; second and third funicular joints subequal, slightly more than twice as long as broad, distinctly shorter than the first joint. Thorax rather long; pro- and mesonotum, especially the latter, very convex and rounded above, the promesonotal suture strong and impressed, the pronotum without the neck more than twice as broad as long; the mesonotum subcircular; mesoëpinotal impression in profile short, acute and rather deep; epinotum small, much lower than the mesonotum, as broad as long, feebly convex, sloping, without distinct base and declivity. Petiole about twice as high as long, the scale distinctly inclined forward, moderately thick, with flat anterior and posterior surfaces, convexly bevelled above, the superior border entire, broadly arcuate, not sharp, the sides straight and converging ventrally. Gaster large, first segment subtruncate.

Moderately shining; mandibles coarsely, longitudinally rugose, with coarse, elongate punctures between the rugæ. Head, thorax and legs finely and regularly reticulate; the meso- and metapleuræ more coarsely; clypeus, cheeks and front finely and sharply longitudinally striate. Petiole and gaster smoother and more shining, the latter very finely, transversely shagreened and sparsely punctate; antennal scapes subopaque, coarsely reticulate, or granular.

Hairs yellowish, short, very sparse, erect on the head, pronotum and gaster, long on the clypeus and gula but not forming a psammophore; shorter, more numerous and appressed on the appendages, the scapes with a few short erect hairs and the gaster with sparse appressed hairs representing a coarse but very dilute pubescence.

Mandibles, head, thorax, petiole and appendages red; anterior border of pronotum, scapes, coxæ, femora, epinotum and petiole darker, brown; gaster black, with pronounced metallic green reflections. In some specimens the infuscation is deeper and more extensive on the thorax, invading the mesonotum and occiput.

Worker minor. Lenth 3.5-4.5 mm.

Head wihout mandibles scarcely broader than long, with straight, subparallel sides, sharp anterior corners and the posterior border and corners together broadly arcuate. Clypeus with the anterior border more projecting in the middle and even less distinctly sinuate. Antennæ more slender than in the major, extending about half their length beyond the posterior border of the head. Eyes larger and slightly more convex. Thorax like that of the major, but the promesonotum less convex, the pronotum proportionally longer, the epinotum above straight and sloping, convex only where it rises from the mesoëpinotal impression and at its posterior end. Petiole with lower, thicker scale than in the worker major.

Sculpture and pilosity very similar, but there are no erect hairs on the scapes and the appressed hair, or dilute pubescence on the tip is shorter and sparser.

Black; gaster with metallic green reflections; mandibles, cheek, gula, antennæ and legs castaneous; posterior borders of gastric segments yellowish.

Several specimens taken by Dr. Darlington and myself from a single nest under a stone near White Hill (X.23.'31) and three taken by Mr. Glauert at City of York Bay (XII.13.'32).

This species closely resembles *M. iridescens* Emery but the worker major is quite different in its more slender stature, smaller and differently shaped head, less emarginate clypeus, shorter frontal groove, coarser sculpture, striolate cheeks, shorter scapes and blunter petiolar scale. It differs from *M. curtus* Forel in its larger size, smaller head, longer scapes, less distinct clypeal emargination, more posteriorly placed eyes and in lacking pubescence on the thorax. It differs from *M. constans* Santschi in its larger eyes, less emarginate clypeus, longer scapes, more pronounced mesoëpinotal impression, thicker and less acute petiolar scale and metallic gaster.

Melophorus turneri Forel subsp. **perthensis** subsp. nov.

Worker major. Length 4.5-5 mm.

Very similar to the subspecies *candidus* Santschi from Victoria but somewhat larger, with mandibles more strongly bent at the base, antennal scapes extending somewhat more than twice their greatest diameter beyond the posterior border of the head and the clypeal border more produced in the middle and not emarginate. Petiolar scale prolonged and narrowed upward, with distinctly emarginate superior border. Epinotal base and declivity forming a distinct obtuse angle in profile, the former convex and little more than half as long as the straight, sloping declivity. Pilosity much less developed than in *candidus*, absent on thorax and petiole and very short

and sparse on the legs, the tibiæ with a row of four or five bristles on their flexor surfaces. Head, thorax, petiole, coxæ and antennæ brownish red or reddish brown, legs brighter yellow or less reddish than in *candidus*. Gaster with metallic blue-green reflections which are quite as vivid as in the typical *turneri*, posterior edges of segments yellowish.

Worker minor. Length 3-3.5 mm.

Very similar to the worker major but the smaller head is proportionally narrower, being about one-fourth broader than long. Antennal scapes extending nearly half their length beyond its posterior border. Promesonotum less, base of epinotum more convex, the latter longer in proportion to the declivity. Petiolar scale decidedly thicker, lower and blunter, scarcely produced at the summit, which is impressed but not emarginate.

Sculpture and pilosity as in the worker major; head, thorax and petiole darker and more brown, as are also the appendages.

Several specimens taken by Mr. Glauert on Rottnest Island in December, 1931. This subspecies is common also in the sandy portions of King's Park, Perth, which may be regarded as the type-locality. Like most other species of Melophorus it makes flat, excentric cräter nests. The worker major of the subspecies *aesopus* Forel from Central Australia differs from that of *perthensis* in not having the scapes reaching beyond the posterior border of the head, the eyes are nearer the middle of the sides and the gaster is less metallic. There are in my colletion several undescribed forms of *turneri*, which seems to constitute a "Formenkreis" of extensive range on the Australian continent.

Notoncus gilberti Forel subsp. *gracilior* Forel.

Worker (undescribed). Length 3-4 mm.

Head slightly longer than broad, subrectangular, very nearly as broad in front as behind, with straight posterior border and slightly convex sides. Eyes feebly convex, their anterior orbits at the median transverse diameter of the head; ocelli minute, rather widely separated. Mandibles stout, with convex external borders, their masticatory borders with six teeth, all stout, except the third from the tip, which is minute. Clypeus convex and carinate in the middle, its anterior border broadly rounded and feebly and rather broadly sinuate in the middle. Antennal scapes extending fully twice their greatest diameter beyond the posterior corners of the head; first funicular joint as long as 2 and 3 together, joints 2-10 nearly one and one-half times as long as broad, terminal joint slightly shorter than the two preceding together. Pronotum without the neck more than twice as broad as long, produced on each side as a broad, blunt, subtriangular protuberance; mesometanotum in profile straight and horizontal, interrupted by the impressed mesometanotal suture; mesonotum from above broadly elliptical, truncated posteriorly, longer than broad; metanotum semicircular; metaëpinotal incision deep, overhung by the posterior, swollen end of the metanotum; epinotum small and low, concave and sloping in the middle, on each side with a strong, thick, rounded, longitudinal thickening or welt so that in profile the base seems to be convex and horizontal, shorter than the abrupt, concave declivity. Petiole less than twice as high as long, the scale in profile cuneate, the anterior and posterior surfaces convex, the apex more compressed and narrowed, the superior border acute and broadly excised. Gaster elliptical. Legs moderately long.

Shining; mandibles finely and superficially striate, very sparsely punctate; clypeus, cheeks and front nearly as far back as the anterior ocellus sharply, longitudinally striate; frontal area and remainder of head smooth and shining, the latter very sparsely punctulate; thorax very smooth and shining, except the neck and extreme anterior border of the mesonotum, which are transversely, and the pleuræ which are in places indistinctly, longitudinally striate. Petiole and gaster smooth and shining, sparsely punctulate; legs more shagreened, with coarser, piligerous punctures, antennal scapes very finely granular, subopaque.

Hairs yellowish, bristly, very sparse, erect and of uneven length on the body and scapes; more numerous and oblique on the legs; pubescence fine and appressed, present only on the scapes, middle and hind coxæ; gaster with some appressed and very short hairs.

Brownish red, gaster blackish or dark brown; femora, tibiæ and in some specimens also the thorax and posterior portion of the head infuscated; thoracic sutures, trochanters, knees, tarsi and posterior borders of gastric segments yellowish; mandibles, except the teeth, which are black, clypeus and cheeks yellow.

Several workers and a female taken by myself near Government House nesting under stones (X. 22, '31), workers and females collected in the vicinity of Perth (King's Park, Monger's Lake and Cottesloe Beach) and three workers from Geraldton.

Forel based this form on a single winged female from Fremantle and regarded it as a mere variety of *gilberti*, originally described from MacKay, Queensland, though he admitted that it might prove to be a subspecies when the worker was found. It seems to me to deserve this rank for geographical reasons and because the worker differs from that of the typical *gilberti*, of which I possess a co-type specimen, in its smaller size (*gilberti* measures 4.8 mm.), less deeply emarginate clypeus, less developed pronotal protuberances, less swollen metanotum, smaller and less sharply angular epinotum, lower petiolar scale, less striated front, smooth mesonotum, yellow instead of red mandibles, clypeus and cheeks, less abundant pilosity, etc. I have not seen the female of the typical *gilberti*, but according to Forel it measures 6.5 mm., its head is as broad as long, the scapes do not extend beyond the posterior border and joints 3-10 of the funiculus are as broad as long, whereas the female *gracilior* measures only 5.5 mm., its head is longer than broad, the antennal scapes extend nearly twice their greatest thickness beyond the posterior border, joints 3-10 of the funiculi are longer than broad and the petiolar scale is less thickened ventrally.

There are in my collection, workers of two forms of *gilberti* from eastern Australia, which closely resemble *gracilior* and may be here briefly described:

Subsp. **annectens** subsp. nov.

Of the same size and colour as the typical *gilberti* but the sculpture more like that of *gracilior*, the meso-, meta- and epinotum microscopically striolate, much more finely than in *gilberti* and slightly less shining than in *gracilior*. Pronotal protuberances more angular and more compressed even than in *gilberti*; epinotum in profile as long as high, with subequal base and declivity meeting at nearly a right angle. Pilosity as in *gracilior*, the emargination of the clypeus and superior border of the petiolar scale as in the typical *gilberti*.

Numerous workers from Enoggera (Wheeler, IX. 14, '14) and Brisbane (H. Hacker), Queensland.

Var. **manni** var. nov.

Of the same size as *gracilior*. Clypeal and petiolar emarginations deep. Pronotal protuberances higher, more compressed and with more acute tips. Antennal scapes slightly longer. Mandibles, cheeks and antennæ yellow as in *gracilior*. Striolation of meso- and metanotum even feebler than in *annectens*.

Six workers collected by Dr. W. M. Mann at Como, near Sydney, New South Wales, and three by myself (XI. 21, '14) at Hornsby in the same part of the Commonwealth.

Plagiolepis lucidula sp. nov.,

Worker. Length 1—1.5 mm.

Head subtrapezoidal, longer than broad, narrower in front than behind, with straight posterior border, broadly rounded posterior corners and nearly straight sides. Eyes rather large, feebly convex, placed distinctly nearer the posterior than the anterior corners. Mandibles narrow, with oblique 6-toothed masticatory borders, the first, fourth and sixth tooth larger than the others. Clypeus rather short, convex, carinate at the base, its anterior border broadly rounded and entire. Frontal area very distinct, triangular, longer than broad; frontal groove tenuous, distinct as far back as the anterior ocellus. Antennæ slender; scapes extending one-fifth their length beyond the posterior border of the head; funiculi enlarged distally, first joint twice as long as broad, thicker than joints 2 and 3; joint 2 as broad as long, 3 longer, 4 to 6 about one and one-half times as long as broad, 7 to 9 shorter, terminal joint swollen, nearly as long as the three preceding together. Thorax short but not stout, broad through the pronotum which is twice as broad as long without the neck; mesonotum narrower, nearly one and one-third times as broad as long, parallel-sided; mesometanotal suture obsolete or indistinct; metanotum very short, its spiracles prominent, separated by a distance equal to only three times their diameter; metaëpinotal suture distinct, epinotum broader than the mesonotum, broader behind than in front, with straight sides. In profile the mesonotum is convex, higher than the pronotum, the metanotal impression shallow, the epinotum long, with the base convex and only about one-fourth as long as the flat, sloping declivity into which it passes without a distinct angle; seen from behind the declivity is broad below, narrowed and rounded above and submarginate at the sides. Petiole low, its scale small, strongly inclined forward and rather thick, its superior border from behind semicircular above. Gaster broadly elliptical, the first segment large, overlying the petiole.

Shining; mandibles finely shagreened and coarsely punctate; remainder of body very finely and superficially punctulate, the legs and scapes more densely than the body.

Erect hairs sparse, present only on the mandibles and clypeus where they are yellowish, and on the gaster where they are brown and distinctly coarser; pubescence pale, very fine and appressed on the body, not sufficiently dense to conceal the shining integument, denser on the appendages.

Castaneous brown; head somewhat darker than the thorax and gaster; mandibles yellow, with reddish teeth; scapes pale brown; palpi, labium and maxillæ white; tarsi and articulations of legs sordid yellow.

Described from six workers, which I found under stones at Lady Edeline Beach, Rottnest Island (X. 23, '31). The only other Plagiolepis described from Australia is *quadrimaculata* Forel from McKay, Queensland, a poorly

differentiated variety of *exigua* Forel, which is really an Indian and Indonesian species. I am therefore adding descriptions of three other forms which suggest that the Old World genus Plagiolepis may be well-represented in the Australian fauna. These ants are easily overlooked owing to the number of minute and similarly coloured species of Iridomyrmex, Tapinoma, Bothriomyrmex or Nylanderia encountered almost everywhere in the Australian bush.

Plagiolepis squamulosa sp. nov.

Worker. Length 1.5—2.5 mm.

Head subrectangular, slightly longer than broad, slightly narrower in front than behind, with sinuous posterior border and nearly straight sides. Eyes rather large, feebly convex, placed distinctly nearer the posterior than the anterior corners. Mandibles rather stout, convex, 6-toothed, the apical tooth long, the others small and subequal. Clypeus large, convex but not carinate in the middle, the anterior border advanced, rounded and entire. Frontal area distinct, rather large, triangular, as broad as long; frontal groove distinct, impressed, extending back to the anterior ocellus. Antennæ slender; scapes reaching fully one-fourth their length beyond the posterior border of the head; funiculi only feebly enlarged at the tip; first joint two and one half times as long as broad, nearly as long as joints 2 to 4 together, joint 2 small, as long as broad, 3 distinctly shorter, 4 to 9 about one and one-half times as long as broad, the terminal joint longer than the two preceding together. Thorax somewhat more than twice as long as broad, broadest through the pronotum, which is less than twice as broad as long, its sides convex and bluntly angular; mesonotum subrectangular, a little broader than long; mesometanotal suture obsolete; metanotum very short, its spiracles small, not strongly projecting, fully four times as far apart as their diameter; metaëpinotal suture distinct; epinotum broader than long, subrectangular, scarcely narrower in front than behind. In profile the mesonotum and posterior portion of the pronotum are nearly straight and horizontal above, the anterior portion of the pronotum steep, the impression at the metanotum feeble, the epinotum with very short, nearly horizontal base, passing gradually into the declivity, which is five times as long as the base, and very sloping, straight anteriorly and distinctly concave posteriorly. Petiole small; its scale low, strongly inclined forward, rather thin, with sharp, broadly rounded superior border. Gaster oval, voluminous, with pointed tip; first segment large, overlying the petiole. Legs slender.

Subopaque and lustrous; mandibles very finely striated and coarsely punctate; head, thorax and gaster sharply, regularly and microscopically reticulate, the surface appearing finely squamulate, especially on the gaster where the reticulations are transverse; appendages with similar but even finer sculpture.

Pilosity and pubescence pale, whitish; the former very sparse, erect, present only on the mandibles, clypeus and gaster; the pubescence very fine, short and appressed, rather dense on the head, thoracic dorsum and appendages, sparser on the gaster.

Dark brown; head darker than the thorax which is a shade darker than the gaster; mandibles, sides of clypeus, scapes, first funicular joint, trochanters, knees and tarsi brownish yellow.

Described from nine specimens which I found under a stone at the foot of the huge sand dunes south of Geraldton, Western Australia (X 8, '31). Two of the specimens are honey-storing repletes, with the gaster greatly distended.

Plagiolepis clarki sp. nov.

Worker. Length 1—1.5 mm.

Head subrectangular, slightly longer than broad, very nearly as broad in front as behind, with nearly straight posterior border and feebly convex sides. Eyes small, flat, near the middle of the sides, less than half as long as their distance from the anterior corners of the head, with only about seven facets in their longest diameter; ocelli very minute. Mandibles rather narrower and convex, 6-toothed, the first, fourth and sixth tooth larger, the fifth very minute. Clypeus short, convex but not carinate in the middle, its anterior border not projecting, broadly rounded and entire. Frontal area distinct, triangular, longer than broad; frontal groove shallow and rather indistinct. Antennæ short; scapes reaching only to the posterior border of the head; funiculi enlarged at the tip; first joint large, as long as joints 2 to 4 together; 2 and 3 small and nearly twice as broad as long; 4 to 9 distinctly broader than long, the terminal joint as long as the four preceding together. Thorax short; pronotum nearly twice as broad as long, with sloping humeri; mesonotum convex, transversely elliptical, somewhat less than twice as broad as long; mesometanotal suture obsolete; metanotum very short and indistinct, its spiracles prominent, separated by a distance equal to about five times their diameter, metaëpinotal suture very distinct; epinotum as broad as long, parallel-sided. In profile the anterior end of the pronotum rises steeply, its posterior end, the mesonotum and base of the epinotum forming a flat curve, with only a feeble impresion at the metanotum, which is hidden in profile by the prominent spiracle; epinotum long and sloping, the base very short, not distinctly marked off from the declivity. Petiole with higher and less anteriorly inclined scale than in the two preceding species, cuneate in profile, flattened behind, anteriorly concave below and convex above, with sharp superior border, which from behind is broadly rounded, with straight, ventrally converging sides. Gaster large, oval, pointed posteriorly, its first segment bulging forward, overlying the petiole and with a deep impression for its accommodation. Legs rather stout.

Subopaque, somewhat lustrous or glossy; very finely and microscopically punctulate; clypeus smooth and shining; mandibles with elongate punctures.

Hairs and pubescence white, the former very sparse, erect or suberect, confined to the clypeus, the tip of the gaster and the posterior borders of its segments. Pubescence short, fine, appressed, moderately dense over the whole surface of the body and appendages and concealing the shining integument.

Brownish yellow or yellowish brown; mandibles, palpi, clypeus, antennæ and legs, including the coxæ, pale yellow.

Female (deälated). Length 3 mm.

Head as broad as long and more rectangular than in the worker; eyes large, moderately convex, longer than their distance from the anterior corners. Antennal scapes extending a little beyond the posterior border of the head. Thorax large, broader than the head, about one and two-thirds longer than broad; mesonotum flattened above, one and one-third times broader than long, broadly arcuate in front, straight behind; epinotum with moderately convex base, which is about half as long as the declivity. Petiolar scale erect, cuneate in profile above, where it is compressed anteroposteriorly and curved backward, so that it is convex in front and concave behind, with acute superior border. From behind the latter is straight or slightly sinuate in the middle, with rounded sides.

Stigmacros aemulus Forel.

Female (deälated; undescribed). Length 2-2.6 mm.

Resembling the worker. Head more rectangular, not longer than broad and less narrowed anteriorly. Eyes larger but not more convex than in the worker. Thorax similarly flattened above, about twice as long as broad, as broad through the wing insertions as the head; pronotum more than twice as broad as long, its posterior portion semicircular, embracing the anterior end of the mesonotum which is broader than long, narrowed behind, with excised sides; scutellum small and rather flat; base of epinotum two and one-half times as broad as long, with broadly excised, marginate posterior border; declivity one and two-thirds times as long, flat, more sloping than in the worker, with the lateral, spiracle-bearing teeth stouter. Petiolar scale large, broad, with distinctly sinuate superior border, in profile as high as the thorax, fully three times as high as thick and scarcely thinner above than below, with convex anterior and slightly concave posterior surface. Gaster large, broadly elliptical, its first segment truncated anteriorly.

Sculpture, pilosity and colour as in the worker, but the mesonotum is smoother and more shining and the thorax has the meso- and metapleuræ, the scutellum, metanotum and epinotum, except its superior corners, black or infuscated; the mesonotum is also more or less diffusely infuscated, or with three broad fuscous vittæ, and the pronotum may be spotted or clouded with fuscous.

Two females which I found nesting under a stone at Lady Edeline Beach, Rottnest Island (X. 23, '31) and one female and three workers running on bark of *Callitris robusta* trees near the Tourists Camp (X. 24, '31). The type-locality of the species is Fremantle. I have examined numerous workers and females taken by Mr. John Clark in this and other Western Australian localities (King's Park, Perth; Mundaring Weir, Hovea and Albany).

Camponotus (*Tanæmyrmex*) *testaceipes* F. Smith.

Numerous workers and a few deälated females taken from several colonies by Dr. Darlington and myself in sandy places on Lady Edeline Beach (X.23.'31) and at Longreach Bay (X.24.'31). Mr. Glauert has also contributed numerous specimens from the west end and other parts of the island.

C. testaceipes, originally described from King George Sound, is common locally along the West Australian coast. I have taken it at Geraldton, in several localities in the Darling Range (National Park, Kalamunda, Mundaring Weir), at Perth and Margaret River. There is in the Museum of Comparative Zoology a long series of workers collected by W. S. Brooks at Denmark. It prefers sandy soil, nesting in large, exposed craters 7 to 10 inches in diameter or about the roots of grass tussocks, more rarely under stones. It is evidently nocturnal. At Geraldton specimens were obtained only by digging down several inches into the sand. A colony comprises about 50 to 75 individuals. The largest workers are aggressive and bite rather severely.

Camponotus (*Myrmophyma*) *chalceus* Crawley.

Many workers and females taken by Mr. Glauert at Bathurst Point (III.28.'32) and other localities on the island and numerous workers by myself in a Pittosporum log at Longreach Bay (X.24.'31). I have found

Sculpture much as in the worker, but the mesonotum is smoother and more shining.

Pilosity and pubescence yellowish, the former as in the worker, the latter much longer and coarser, especially on the gaster.

Head, thorax and gaster brown, the gaster slightly paler; otherwise like the worker.

Male. Length 1.5-1.7 mm.

Head broader than long through the eyes, which are very convex and nearly half as long as the sides; cheeks about one third as long as the eyes, converging anteriorly; postocular portion of head rounded-subrectangular, more than twice as broad as long, with prominent, widely separated ocelli. Mandibles small, slender, falcate and edentate. Clypeus short, three times as broad as long, evenly convex, with nearly straight anterior border. Frontal area broader than long; frontal groove very distinct. Antennæ slender; scapes reaching a little beyond the posterior ocelli; funiculi gradually thickened distally; joints 2 and 3 slightly broader than long, 4 to 10 slightly longer than broad, 11 as long as the three preceding together. Thorax large, broader than the head; mesonotum subcircular, somewhat broader than long, anteriorly very convex and overarching the pronotum; flattened and horizontal posteriorly; epinotum convex, rather abruptly sloping, with indistinct base and declivity. Petiolar scale erect, small and very thin, with sharp superior border, from behind subrectangular, with straight superior border and rounded superior corners. Gaster elongate-elliptical. Stipites of genitalia narrow, triangular and pointed; volsellæ slender, geniculate and deflected; sagittæ large, flat, blade-shaped, their truncated tips terminating above in an acute point. Legs slender. Wings large and broad, with large peterostigma.

Sculpture and pilosity much as in the worker but the dorsal surface of the thorax and gaster more shining owing to the much sparser pubescence on these parts.

Colour like that of the worker, except that the head and thorax are brown and darker than the gaster; antennæ and legs also darker than in the worker. Wings white, with white veins and pterostigma.

Described from seven workers and fifteen males taken by Mr. John Clark at Mundaring Weir, Western Australia (type-locality), four workers from Margaret River (XI. 4, '31) and two colony-founding females from Pemberton (XI. 13, '31), taken by myself. There is little doubt that the females belong to this species, which, judging from the pale colouration and small eyes of the worker, have much the same hypogaeic habits as the species of Brachymyrmex of North and South America.

Plagiolepis clarki subsp. **impasta** subsp. nov.

Worker. Length 1-1.4 mm.

Very similar to the worker of the typical *clarki* but differing in having slightly shorter antennal scapes, which do not quite reach the posterior border of the head, and in having the third to ninth funicular joints distinctly broader in proportion to their length. Especially the thorax and gaster more shining, owing to the somewhat sparser punctulation and pubescence, the latter longer and less appressed, conspicuously longer on the gaster. Yellow colouration of body less brownish than in the typical *clarki*.

Three specimens taken by Mr. J. C. Wiburt at the Jenolan Caves, in the Blue Mountains of New South Wales.

this beautiful and inoffensive ant also at Kalamunda and Roleystone, in the Darling Range, in King's Park, Perth, and at Margaret River, always nesting in logs, or in the stumps of Xanthorhoea. Mr. John Clark collected it at Ludlow. The types were taken by Rowland Turner at Yallingup. In life the head and thorax of the worker have a more or less greenish tint, the gaster varying from bronze to metallic green or purple. The wings of the female (not mentioned by Crawley) are heavily infuscated, especially along their anterior borders, and have the veins and pterostigma dark brown.

Camponotus (Myrmophyma) claripes Mayr.
subsp. *minimus* Crawley.

Workers and deälated females from several colonies nesting under stones in the following localities: Government House (X.21.'31), Lady Edeline Beach (X.23.'31), Longreach Bay (X.24.'31) (Wheeler) and City of York Bay (Glauert).

Camponotus (Myrmophyma) walkeri Forel.

This species was recorded by Mr. John Clark from Rottnest Island.

Camponotus (Myrmophyma) darlingtoni sp. nov.

Worker maxima: Length 8-9 mm.

Head subtrapezoidal, as broad as long or somewhat broader than long, high and convex above, flat below, with straight posterior and concave occipital border and convex sides. Eyes small, flat; ocelli present but minute. Mandibles stout, convex, with six subequal teeth. Clypeus subcarinate, its median section as long as broad, its anterior border straight in the middle, deeply sinuate on each side, not projecting beyond the anterior borders of the cheeks. Frontal area triangular, indistinct; frontal groove very distinct; frontal carinæ approximated anteriorly, more separated and subparallel posteriorly. Antennæ slender; scapes not extending beyond the posterior border of the head. Thorax short, its dorsal outline as far back as the epinotal angle evenly arcuate; promesonotal suture not impressed; metanotum present, but poorly defined posteriorly; epinotum laterally compressed, in profile with subequal base and declivity meeting at a distinct obtuse angle, the base straight and slightly sloping, the declivity more so and slightly concave. Petiolar scale rather high and narrow, thin, with convex anterior and flat posterior surface, the superior border sharp and compressed, from behind semicircularly rounded, the sides feebly convex, converging ventrally. Gaster broadly elliptical. Legs moderately long, the fore femora incrassated; middle and hind tibiæ subterete, with a series of five or six short spines on their flexor surfaces.

Finely and sharply shagreened, shining, gaster and posterior portion of head more so than the remainder of the body and the appendages; mandibles subopaque, coarsely punctate and like the clypeus and anterior portion of the head more coarsely shagreened or reticulate than the posterior portion. Cheeks, front and thoracic dorsum sparsely punctate; pleuræ finely longitudinally striate; gaster delicately, transversely striolate, with sparser, piligerous punctures.

Hairs white, erect, rather short, flexuous, very sparse; pubescence appressed, very short and sparse on the gaster and cheeks, longer on the pronotum, mesonotum and head, short and abundant on the antennæ, longer and coarser on the legs, especially on the tibiæ, where it is less appressed.

Black; mandibles, clypeus, anterior border of cheeks, antennæ, neck and posterior border of pronotum castaneous; posterior borders of gastric segments rather broadly, sordid whitish. Legs, including the coxæ, testaceous; tibiæ slightly darker than the femora, tarsi red.

Worker media. Length 7-7.5 mm.

Head much smaller than in the maxima, about one-sixth longer than broad, less narrowed anteriorly, with feebly and evenly rounded sides. Antennal scapes extending nearly one-third their length beyond the posterior border of the head. Pronotum semicircular anteriorly, flattened above, with more distinctly marginate sides; in profile with the dorsal outline broadly arcuate and made up of four subsequal straight or nearly straight segments corresponding to the pronotum, mesonotum, base and declivity of epinotum, the anterior end of the mesonotum raised rather abruptly above the posterior end of the pronotum and both the base and the slightly shorter declivity of the epinotum distinctly concave so that the angle between them is pronounced. Petiolar scale narrower and thicker than in the maxima, with blunt superior border.

In sculpture, pilosity and colour very much like the maxima but the legs are more brownish testaceous and the basal halves of the coxæ and femora are fuscous, the pale posterior borders of the gastric segments narrower.

Worker minima. Length 4-5.5 mm.

Very similar to the media but the head longer, nearly one and one-third times as long as broad, with more subparallel sides, more convex eyes and the antennal scapes extending nearly half their length beyond the posterior border. Sides of pronotum sharply marginate; dorsal outline of thorax similar, but the epinotum lower and more sloping and its base straight and nearly twice as long as the declivity. Petiolar scale much thicker and narrower, in profile almost subcuboidal, with straight anterior and posterior surfaces and horizontal, feebly rounded superior surface.

Pilosity and colouration as in the media, but the head and thorax more opaque and more sharply shagreened; legs usually even more brownish.

Female (deälated). Length 11 mm.

Head trapezoidal, very nearly as broad as long, with straight posterior border and nearly straight, anteriorly converging sides. Eyes small but somewhat more convex than in the maxima. Antennal scapes reaching about one-fifth their length beyond the posterior border of the head. Thorax oval, about twice as long as broad, anteriorly distinctly broader than the head; mesonotum slightly broader than long, flattened posteriorly; epinotum short, its base convex, much shorter than the steep, concave declivity into which it passes without an angle. Petiolar scale like that of the maxima, but thicker and broader, compressed above, with its superior border somewhat produced upward in the middle. Gaster elongate-elliptical.

Sculpture, pilosity and colour as in the maxima, but the whole pronotum castaneous.

Described from numerous specimens found nesting under logs and stones at Margaret River, Western Australia (type-locality) during October and November, 1931, a single worker maxima and several minimæ taken by Dr. Darlington and myself at Longreach Bay (X.24.'31) and Government House, Rottnest Island (X.21.'31), and a single small worker from King's Park, Perth (X.15.'31).

I have specimens of nearly all of the more than fifty described species, subspecies, and varieties belonging to the Australian subgenus Myrmophyma as defined by Emery in the "Genera Insectorum," but *darlingtoni* differs from all of them, particularly in the structure of the thorax of the media and minima, with its peculiarly broken dorsal outline.

Camponotus (*Colobopsis*) *gasseri* Forel.

subsp. **caloratus** subsp. nov.

Soldier: Length 5-6.5 mm.

Differing from the typical *gasseri* in its smaller average size, smaller head, less convix pro- and mesonotum, shallower metanotal impression, slightly thinner and dorsally less obtuse petiolar scale and in coloration, the red of the anterior portion of the head being more vivid, or more yellowish and extending farther back of the truncation over the cheeks and the whole front. The ventral portions of the thorax and petiole, and the dorsal sutures of the former are red or reddish brown and the bases of the first and second gastric segments are ivory yellow. The antennæ and legs are also distinctly paler, being red or brownish red.

Worker: Length 3-4 mm.

Also smaller than the worker *gasseri*, with the same differences as the worker in the coloration of the thorax and appendages, the cheeks and often also the clypeus yellowish red or reddish yellow like the mandibles. In some specimens only the posterior half of the head is dark brown or black and the thorax is red, with only the discal portions of the pro-, meso- and epinotum black.

Female (deälated). Length about 7 mm.

Decidedly smaller than the female of the typical *gasseri* which measures 9mm. Colouration like that of the soldier, but with only the sutural regions reddish. The ivory yellow portions of the first and second gastric segments are more extensive and the third segment has an ivory yellow spot at the base on each side.

Male. Length 4.5 mm.

Black, with very dark brown legs and antennal scapes; mandibles, funiculi and genitalia dull piceous; wings whitish with very pale brown veins and pterostigma. Fore femora strongly bowed.

Described from many specimens from several populous colonies found nesting in the wood just under the bark of Leptospermum, Callitris and Acacia trees near Government House (X.22.'31). The nest entrances were small, perfectly circular holes in the bark. No doubt, these entrances are guarded by the soldiers as in other species of Colobopsis.

C. gasseri was originally described from Perth. I have taken specimens near Pemberton, Western Australia, nesting in the branches of a huge, recently felled Karri tree (*Eucalyptus diversicolor*), and have received others collected by Mr. John Clark at Mundaring Weir. The species is widely distributed over southern and eastern Australia from Queensland to Tasmania. The Tasmanian form was described by Forel as var. *lysias*, that from Queensland as subsp. *obtusitruncatus*. The specimens which I have taken in New South Wales and have received from several localities in South Australia are only slight variants of the typical form from Western Australia.

Polyrhachis (*Campomyrma*) *sidnica* Mayr

var. *perthensis* Crawley.

Fourteen workers and a deälated female from a single colony nesting under a stone near Government House (X. 21, '31).

The undescribed female of this variety measures about 8 mm. and differs from the worker, apart from the usual caste characters, in having the pair of lateral petiolar spines even longer, stouter and more curved, and the median pair reduced to very small, broad teeth.

Polyrhachis (*Campomyrma*) *micans* Mayr

subsp. *ops* Forel.

A single deälated female found running on the ground near White Hill (X. 23, '31).

Paratrechina (*Nylanderia*) *minutula* Forel.

Numerous workers and a deälated female found nesting under stones at Lady Edeline Beach (X. 23, '31) and several workers taken by Mr. Glauert at City of York Bay (XII. 13, '32).

The worker of this species varies considerably in colour from pale brownish yellow to rather dark brown. The female measures nearly 3 mm. and is pale castaneous with more yellowish mandibles, antennæ and legs. I have seen worker specimens from a wide area in Australia, e.g. Bulli Pass, New South Wales (Wheeler); Adelaide, South Australia (A. M. Lea) and Bribie Island, Queensland (H. Hacker). The cotypes, of which I possess one, are from New South Wales (Froggatt). Varieties are known from the Bismarck Archipelago, the island of Guam and the island of Formosa.

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8.—A NEW METHOD FOR THE DETERMINATION OF FERROUS IRON IN REFRACTORY SILICATES.

By H. P. Rowledge, A.W.A.S.M., A.A.C.I.

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INTRODUCTION.

The methods for the determination of ferrous iron in silicates have always presented difficulties to the mineral chemist and many investigators have carried out experiments with a view to improving them. The chief difficulties encountered are, the prevention of oxidation during the determination, and the incomplete decomposition of the more refractory silicates.

The determination of ferrous iron is an important question when deciding the constitution of the mineral, especially in the presence of both ferrous and ferric iron. The investigations described in this paper were carried out in an endeavour to evolve a method whereby the refractory silicates are completely decomposed without oxidation of the ferrous iron.

A survey of the methods in the literature at the disposal of the author shows that decomposition of the mineral is effected by either sulphuric acid or a mixture of hydrofluoric and sulphuric acids under varying conditions. In these investigations, the decomposition of the mineral was attempted by sintering or fusing in sealed glass tubes with a number of non-oxidising fluxes, with the final result that decomposition was effected by fusion with sodium metafluoborate.

Part I. of the paper describes the new method and its application to almandine garnet, the constitution of this mineral and the general application of the method to other minerals.

Part II. gives a brief description of the published methods, the necessity for the investigation, the complete investigations from which the new method was evolved and a consideration of the preparation, analysis and constitution of the fluoborates.

PART I.

The Method.

The determination of ferrous iron by this method depends on: -

1. The decomposition of the mineral by fusion with sodium metafluoborate in sealed pyrex glass tubes.

2. The solution of the fusion in dilute sulphuric acid solution in the absence of air.

3. The titration of the solution with standard potassium permanganate solution in the usual manner for the determination of iron.

Sodium metafluoborate $(NaF)_2.B_2O_3$.—The sodium metafluoborate is prepared by heating together 2 parts of anhydrous sodium fluoride and 1 part

of anhydrous boric acid in molecular proportions in a platinum dish at temperatures between 750° C. and 1050° C. At temperatures under 900° C. the heated pasty mass requires stirring with a platinum spatula. At temperatures over 900° C. a clear fusion is obtained in 5 minutes. Prolonged heating should be avoided above this temperature as fluorine is lost. The fused sodium metafluoborate is finely ground and kept in an air-tight bottle.

Glass Tubes.—The glass tubes are prepared from Pyrex glass tubing ½-inch in diameter, 1/32nd-inch thick and 2½ inches long. One end is sealed in the gas blast and the other end drawn out slightly to thin the glass, allowing sufficient opening to admit a short stemmed glass funnel for the introduction of the flux.

Procedure.—.3 to .5 grm. of the mineral, ground to pass 90-mesh sieve, is mixed with 5 times its weight of sodium metafluoborate on a glazed paper. The mixture is introduced into the glass tube by means of a short-stemmed glass funnel. Brush the paper and funnel, being careful to avoid the introduction of organic matter. The tube is gently tapped to pack the mixture, covered with .5 grm. of sodium metafluoborate, and quickly sealed. The sealed glass tube, containing the mixture of mineral and flux, is placed in a vertical position in a bath of sand and heated in an electric furnace at 950° C. for 15 minutes.

A convenient method of heating is as follows:—A Morgan Battersea "B" fireclay crucible is filled with glass sand (free from FeO). The glass tube is placed in the sand and completely covered. The fireclay crucible is covered with a flat fireclay or asbestos disc and placed in the furnace at the requisite temperature. Under these conditions the shape of the glass tube is perfectly retained and distortion through softening prevented.

The fireclay crucible is removed from the furnace and cooled sufficiently to permit the removal of the glass tube from the sand without distortion.

The hot glass tube containing the fusion is placed upon a fused silica square or in a platinum dish and covered to prevent loss of flying pieces on cooling. When cool, the glass is broken away from the fusion and the larger pieces of fusion broken to about the size of a pin's head.

The solution of the fusion is effected in the following manner:—Whilst the preceding operation is being carried out a solution of air free dilute sulphuric acid is prepared. Place 30 ccs. 10E H_2SO_4 and 150 ccs. distilled water in a 250 cc. flat-bottomed flask. Stopper the flask with a rubber cork through which a bent glass tube drawn to a fine nozzle at one end passes. Boil the solution and cool by placing the nozzle of the glass tube under a seal of sodium bicarbonate solution. When cool, the broken fusion and glass tube is added and the contents of the flask boiled on an asbestos mat over a bunsen burner. The neck of the flask should be held by a clamp, as bumping takes place. Ten minutes boiling should be sufficient for complete decomposition of the fusion. The flask is removed from the burner and allowed to cool under a sodium bicarbonate seal as before.

When cool, the stopper is removed and the solution titrated immediately with a standard $KMnO_4$ solution in the usual manner for the determination of iron.

A blank upon the reagents should be run under exactly similar conditions to the assay.

APPLICATION OF THE NEW METHOD TO ALMANDINE GARNET.

A sample of almandine garnet, Lab. No. 735/32, from the Yabberup District was prepared, analysed, and the ferrous iron determined by both the new fluoborate method and the hydrofluoric and sulphuric acid method as used in this laboratory.

Exp.	Garnet.	Fine.	$(NaF)_2 B_2O_3$	Ratio Flux to Mineral.	Temp.	Time.	FeO.	FeO.
							gms.	%
213	·4	90	2·0	5 : 1	800 850 C	20′	·1276	31·91
218	·4	,,	,,	,,	800 900 C	,,	·1259	31·47
223	·5	Impalpable powder	2·5	,,	,,	,,	·1530	31·60
224	·4	90	2·0	,,	900° 960 C	,,	·1262	31·56
225	·4	,,	2·0	,,	,,	,,	·1276	31·91

FeO by HF and H_2SO_4 method 30.30 per cent.
FeO mean figure by fluoborate method 31.69 per cent.

CONSTITUTION OF GARNET 735/32.

The mean figure 31.69 per cent. FeO was applied to the analysis of garnet 735/32 and the ratio of molecules $RO : R_2O_3 : SiO_2$ calculated and compared with the ratio obtained by using the FeO figure by the HF and H_2SO_4 method.

Theoretically almandine garnet has the following ratio:—
$RO : R_2O_3 : SiO_2 :: 3 : 1 : 3$.

Analysis.	FeO by HF. H_2SO_4 method. %	Mols.	FeO by fluoborate method. %	Mols.
SiO_2	35·29	5,876	35·29	5,876
Al_2O_3	19·25	1888	19·25	1,888
Fe_2O_3	3·31	207	1·77	111
FeO	30·30	4,218	31·69	4,411
MnO	1·47	207	1·47	207
CaO	3·50	624	3·50	624
MgO	3·36	833	3·36	833
H_2O+	·62	344	·62	344
H_2O - ...	–			
TiO_2	3·14	393	3·14	393
Total ...	100·24		100·09	

MICROSCOPIC EXAMINATION.

Small amount of black mineral -Ilmenite.
Smaller amount of red brown mineral Limonite.
Smaller amount of colorless mineral—Quartz.
Traces of amphibole and altered minerals.

RATIO $RO : R_2O_3 : SiO_2$ IN GARNET 735/32.

R_2O_3 after deducting all Fe_2O_3 molecules calculated to limonite and RO after deducting 393 mols. FeO to balance TiO_2 to ilmenite.

	Ratio. RO	:	R_2O_3	:	SiO_2
1. By HF and H_2SO_4 method	2·91	:	1	:	3·11
2. By Fluoborate method	3·01	:	1	:	3·11

All Fe_2O_3 mols. added to R_2O_3 and RO after deducting 393 mols. FeO to balance TiO_2 to ilmenite.

	RO	:	R_2O_3	:	SiO_2
			Ratio.		
3. By HF and H_2SO_4 method	2·62	:	1	:	2·80
4. By Fluoborate method	2·84	:	1	:	2·94

R_2O_3 after deducting all Fe_2O_3 mols. calculated to limonite and RO including all FeO mols. with TiO_2 left uncombined.

	RO	:	R_2O_3	:	SiO_2
			Ratio		
5. By HF and H_2SO_4 method	3·12	:	1	:	3·11
6. By Fluoborate method	3·22	:	1	:	3·11

All Fe_2O_3 mols. added to R_2O_3 and RO including all FeO mols. with TiO_2 left uncombined.

	RO	:	R_2O_3	:	SiO_2
			Ratio		
7. By HF and H_2SO_4 method	2·81	:	1	:	2·80
8. By Fluoborate method	3·04	:	1	:	2·94

Comments.

The ratio of 3.01 : 1 : 3.11 in No. 2 by using the FeO value obtained by the fluoborate method gives a closer agreement with the theoretical ratio of 3 : 1 : 3 than the ratio 2.91 : 1 : 3.11 obtained by using the FeO value obtained by HF and H_2SO_4 method. The recognition of ilmenite and limonite in the sample justifies the calculating of the Fe_2O_3 to limonite and the combining of 393 mols. of FeO to balance 393 mols. of TiO_2 to form ilmenite. The presence of quartz in the sample is shown by the higher ratio for SiO_2, 3.11.

When the Fe_2O_3 molecules are added to the R_2O_3 molecules as in 3, 4, 7 and 8, the ratio of 3 : 1 : 3 is upset, and when the TiO_2 molecules are not combined with FeO molecules as in 5, 6, 7 and 8, the ratio of SiO_2 is less than that of RO which cannot be owing to presence of free quartz in the sample.

The above calculations therefore prove that the figure obtained by the fluoborate method is the correct one.

CHECK FeO DETERMINATIONS ON GARNET 735/32.

New batches of sodium fluoborate were prepared and the method again applied to the almandine garnet sample, Lab. No. 735/32.

Exp.	Garnet 735/32.	Fine	$(NaF)_2B_2O_3$	Ratio Flux to Mineral.	Temp.	Time.	FeO.	FeO.
							gms.	%
244	·3	90	1·5	5 : 1	900°—960°C	20′	·0956	31·87
289	·4	,,	2·0	,,	,,	15′	·1264	31·60
291	·45	,,	2·25	,,	,,	,,	·1417	31·49

The mean FeO figure by fluoborate method in this series is 31.65 per cent. and checks the mean figure of 31.69 per cent. in Experiments 213, 218, 223-5.

THE FLUOBORATE METHOD APPLIED TO OTHER MINERALS.

The determinations up to the present stage have been carried out upon almandine garnet and satisfactory results obtained which are confirmed when the FeO figure is applied to the constitution of this mineral.

To prove the general application of the method to silicate minerals, experiments were carried out on samples of biotite mica, staurolite, axinite and tourmaline. The first one tried, biotite, was chosen on account of the ease with which it is decomposed by HF and H_2SO_4, giving a figure which can be compared with the figure obtained by the fluoborate method. The next tried were staurolite, axinite and tourmaline. These are refractory minerals only being partly decomposed by HF and H_2SO_4 even when finely ground. For comparison with the fluoborate method a figure for FeO was obtained by treating the finely ground product with HF and H_2SO_4, weighing the undecomposed residue and calculating the FeO value upon the weight of decomposed mineral obtained by difference.

BIOTITE SAMPLE.

Analysis, 4064/32, *Holleton.*

	%
SiO_2	34·28
Al_2O_3	19·91
Fe_2O_3	7·25
*FeO	17·24
MnO	·28
MgO	5·53
CaO	·01
Na_2O	·38
K_2O	9·24
H_2O+	3·45
H_2O-	·52
TiO_2	1·67
P_2O_5	·23
Total	99·99

* By HF and H_2SO_4 method.

EXPERIMENT WITH 5 : 1 MIXTURE $(NaF)_2.B_2O_3$: BIOTITE.

Exp.	Biotite. 4064/32	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO gms.	FeO %	Conditions.
317	·3	1·5	900 –960°C.	15′	·0517	17·24	Good fusion. Complete decomposition.

The sodium fluoborate used in this experiment was batch 279 and had been standing in a stoppered bottle for six months after preparation. There was no sign of decomposition or attack upon the glass.

	HF and H_2SO_4 method.	Fluoborate method.
FeO ...	17·24%	17·24%

STAUROLITE SAMPLE.

Analysis, 733/32, Chittering Lake.

	%
SiO_2	30·08
Al_2O_3	49·94
Fe_2O_3	1·56
*FeO	12·98
MnO	·42
MgO	1·54
CaO	·38
Na_2O	·14
K_2O	·06
H_2O + ...	1·92
TiO_2	·90
Total	99·92

* By HF and H_2SO_4 method.

Experiments with 5 : 1 Mixture $(NaF)_2 . B_2O_3$: Staurolite.

Exp.	Staurolite 733/32 —90 mesh.	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
302	·3	1·5	900—960°C.	15′	·0353	11·78	Good fusion. Complete decomposition.
309	·5	2·5	do.	15′	·0583	11·66	do. do.
314	Fine ·5	2·5	do.	15′	·0583	11·66	do. do.

The method and conditions observed were similar to those with garnet and biotite.

	HF and H_2SO_4 method.		Fluoborate method.
FeO	12·98%	...	11·70%

AXINITE SAMPLE.

Analysis, 2413/29, Talbot Bay.

	%
SiO_2	42·14
Al_2O_3	17·67
Fe_2O_3	1·74
*FeO	6·81
MnO	3·09
MgO	2·06
CaO	19·96
B_2O_3	5·56
H_2O + ...	1·56
Total	100·59

*By HF and H_2SO_4 method.

EXPERIMENTS WITH 5 : 1 MIXTURE $(NaF)_2.B_2O_3$: AXINITE.

Exp.	Axinite 2413/29.	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
303	·3	1·5	900—960°C.	15′	·0180	6·00	Good fusion. Complete decomposition.
310	·5	2·5	do.	15′	·0281	5·62	do. do.
312	·5	2·5	do.	15′	·0305	6·11	do. do.
316	·5	2·5	do.	15′	·0288	5·76	do. do.

The method and conditions observed were similar to those with garnet, biotite and staurolite.

	HF and H_2SO_4 method.		Fluoborate method.
FeO	6·81%	...	5·87%

TOURMALINE SAMPLE.

*FeO 12·41%

*By HF and H_2SO_4 method.

EXPERIMENTS WITH 5 : 1 MIXTURE $(NaF)_2.B_2O_3$: TOURMALINE.

Exp.	Tourmaline —90 mesh.	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
290	·4	2·0	900—960°C.	15′	·0492	12·30	Good fusion. Complete decomposition.
294	·3	1·5	do.	15′	·0371	12·36	do. do.

The method and conditions observed were similar to those with garnet, biotite, staurolite and axinite.

	HF and H_2SO_4 method.		Fluoborate method.
FeO	12·41%	...	12·33%

SUMMARY.

A new method for the determination of ferrous iron in refractory silicates is described. It consists of the fusion of the mineral with sodium metafluoborate $(NaF)_2.B_2O_3$ in sealed pyrex glass tubes, the solution of the fusion in dilute sulphuric acid solution and the titration of the solution with standard potassium permanganate solution.

Consistent ferrous iron figures are obtained upon a sample of almandine garnet with different batches of sodium metafluoborate.

The accuracy of the ferrous iron figures obtained is supported by—

1. The calculation of the constitution of the garnet.
2. The results obtained with biotite, a mineral completely and easily decomposed by a mixture of hydrofluoric and sulphuric acids.

The method is applicable to other minerals with satisfactory results. Minerals such as tourmaline, staurolite and axinite, which are not completely decomposed with hydrofluoric and sulphuric acids, are completely decomposed by fusion with sodium metafluoborate without further fine grinding of the -90 mesh product.

PART II.

Before proceeding with a description of the experimental work in connection with this method, a brief description of the existing methods will be outlined and the reasons necessitating an attempt to develop a new method presented.

HISTORY.

In all the known methods for determination of FeO in minerals, the decomposition is effected by either sulphuric acid alone or by a mixture of hydrofluoric and sulphuric acids.

METHODS EMPLOYING SULPHURIC ACID ALONE.

Mitscherlich's Method[2].—In this method the extremely fine ground mineral is heated in a sealed glass tube with a strong sulphuric acid solution (4 parts acid to 1 of H_2O) at a temperature of 200° C. The resulting solution is titrated with standard $KMnO_4$.

Mitscherlich's Method modified[2].—The modification uses a much weaker solution of sulphuric acid to allow for the solution of separated salts, the proportion of acid to water being 1 : 3. The air in the tube is replaced by CO_2 before sealing.

METHODS EMPLOYING SULPHURIC ACID AND HYDROFLUORIC ACID.

Suida's Method.[1]—The mineral is ground until it will remain in suspension in water at least two hours. This finely ground product is decomposed by a mixture of HF and H_2SO_4 in a sealed glass tube. The solution is titrated with standard $KMnO_4$ solution.

Pratt's Method modified.[3]—Pratt uses the coarsest powder that can successfully be decomposed. The mineral is placed in a platinum crucible of 80-100 cc. capacity with a little air free water and about 10 cc. of H_2SO_4 (1 acid to 3 water by volume). Air free hot water is added until the crucible is half full. The crucible is covered, placed upon a triangle and heated at low heat. The air is displaced by CO_2 introduced under the lid, 5-7 ccs. of strong HF added, the cover replaced and the solution boiled for 5-10 minutes. The crucible with contents is then transferred into a titrating vessel containing a cold saturated solution of boric acid in freshly boiled water, and titrated with standard $KMnO_4$ solution. Any undecomposed residue is finely ground and re-treated.

Cooke's Method.[4]—This method is similar to Pratt's modified method in that the mineral is decomposed by H_2SO_4 and HF in an atmosphere of CO_2. More elaborate apparatus (including a water trap) is, however, used to hold the atmosphere of CO_2 around the crucible to prevent oxidation by air. The time of treatment is increased in this method to one hour.

Barneby's Method.[5]—Barneby uses a simplified form of Cooke's apparatus. Steam is used instead of CO_2 to expel the air. The water trap is replaced by a phosphoric acid solution (1:2).

Treadwell's Method.[6]—The decomposition of the mineral in this method is effected in a similar manner to the former methods. The platinum dish containing the mineral is placed in a specially designed lead box and is heated in a paraffin bath at a temperature of 120° C. for about two hours in an atmosphere of CO_2.

W.A. Government Chemical Laboratory Method.—.5 grm. of mineral crushed to pass a 90 mesh sieve is placed in a special platinum crucible of 30 ccs. capacity. 15 ccs. 10E H_2SO_4 and 5 ccs. HF are added to the crucible which is immediately covered. Place the crucible and contents upon a sand bath and boil for seven minutes. Remove and place in a 400 cc. beaker containing 200 ccs. of freshly boiled water in which 1 grm. of boric acid has been dissolved. Detach the lid with a glass rod, stir well and titrate with standard $KMnO_4$ solution.

The special platinum crucible is of 30 ccs. capacity and has a close fitting double lid, each piece of which has a small central aperture and is separated from the other by a plain platinum disc. A platinum wire holder is used for lifting the crucible.

In cases with refractory minerals where incomplete decomposition is obtained, the residue is either weighed and the FeO value obtained by calculation or it is reground and retreated with H_2SO_4 and HF.

COMMENTS.

Mitscherlich's method with H_2SO_4 alone has not proved satisfactory owing to the length of time required for the decomposition of the mineral which, in some cases, as with tourmaline, is never complete, the excessive fine grinding necessary which may cause oxidation,[7] and the difficulties in manipulation.

The methods using HF and H_2SO_4 increase the rate and amount of decomposition, but these acids do not give complete decomposition of refractory minerals, such as tourmaline, even when finely ground. It is necessary to either re-treat the residue after further grinding or weigh the residue and obtain the FeO value by calculation. The former is not altogether satisfactory on account of the possibility of errors introduced due to oxidation and manipulation. The latter may be used in the case of homogeneous minerals, but, generally speaking, it is unsatisfactory owing to doubt as to the composition of the residue.

The main line of investigation in respect to all these methods seems to have been confined to the prevention of oxidation of the FeO from a number of sources during decomposition of the mineral. There does not appear to have been any practicable method evolved in which complete decomposition of the more refractory minerals has been attained even with excessive fine grinding.

It was therefore decided to investigate the possibility of developing a method by fusing the mineral with suitable fluxes.

The Evolution of the Method.

As the decomposition of the mineral is to be effected by fusion with fluxes, the main problems presenting themselves are:—

1. The selection of the fluxes which will not cause oxidation of the ferrous iron.
2. The method to be adopted in carrying out the fusion without oxidation by oxygen from the air.

It was decided, with regard to the latter, to carry out the fusion in sealed combustion glass tubes. The flowing point of combustion glass is about 900° C., therefore the fluxes first considered were those whose melting

points are under this temperature. Later means were devised for heating the glass tubes at temperatures over 900° C., and fluxes of higher melting point were considered. The effect of sintering as well as fusing was also tried. Combustion glass was replaced by pyrex glass.

A study of suitable materials, and their melting points, for fluxes led to preliminary experiments being carried out with potassium hydroxide, sodium hydroxide, and the alkali fluorides. Of these sodium fluoride and potassium fluoride showed the most promise, and further investigations were carried out with these salts alone and in mixtures with potassium acid fluoride, calcium fluoride, and sodium hydroxide. Finally, mixtures of fluorine and boron compounds were tried and resulted in the preparation of sodium metafluoborate, a flux which will completely decompose silicate minerals with satisfactory ferrous iron results.

PRELIMINARY EXPERIMENTS.

A number of trial experiments were carried out upon garnet and tourmaline with KOH, NaOH, KF, NaF, and CaF_2, using glass tubes made from ordinary combustion tubing ½-inch in diameter, to ascertain the best conditions under which to carry out the investigations. The heating was carried out in the direct flame of the bunsen and meker burners and in an electric furnace at temperatures between 700° C. and 960° C. Softening and distortion of the glass tubes, causing complete collapse in some cases, rendered the experiments useless.

To prevent this collapse the glass tubes were placed in a bath of sand and heated in the electric furnace at the above temperatures. This proved satisfactory and was adopted in the subsequent experiments.

The ordinary glass combustion tubing was replaced by pyrex glass tubing, ½-inch diameter, on account of its greater resistance to heat, its ability to withstand change of heat without cracking, its resistance to chemical action and its low iron content.

Method of Procedure.

As a result of the conditions observed in the trial experiments, the following method of procedure was adopted in the subsequent investigations.

Mix the finely ground mineral with the desired amount of flux on a mixing paper and introduce in the glass tube by means of a short-stemmed glass funnel. The tubes are made from pyrex glass tubing ½-inch diameter, 1/32-inch thick and about 2½ inches in length. One end is sealed in the gas blast. The tube containing the mixture is gently tapped, covered with a layer of flux and the open end quickly sealed. Place the tube vertically in a bath of sand with about ¼ inch exposed. The sand bath consists of a Morgan Battersea "B" fireclay crucible filled with glass sand from Lake Gnangara, containing .03 per cent. Fe_2O_3 and no FeO. The size of the glass tube and sand bath is limited to the size of the Gallenkamp's electric furnace used.

The sand bath containing the sealed glass tube and contents is placed in the electric furnace at the desired temperature. At the expiration of the requisite time of heating it is removed and allowed to cool sufficiently so that the glass tube can be removed without distortion.

The hot tube is placed in a 250 cc. stoppered flask containing 30 cc. IOE H_2SO_4 made up to 200 cc. with distilled water in which 1 grm. of B_2O_3 has been dissolved, the whole solution having been boiled and cooled in an

atmosphere of CO_2 as in the usual manner for the determination of iron. The stopper consists of a rubber cork through which a bent glass tube drawn to a fine nozzle passes. The atmosphere of CO_2 is obtained by placing the nozzle of the flask containing the hot solution under a saturated solution of sodium bicarbonate.

Boric acid[12] is added to the solution to render the fluorine inactive by the formation of fluoboric acid (HBF_4) which does not appreciably dissociate to form HF. The plunging of the hot tube into the cold solution causes the glass to crack away and open up the sinter or fusion.

The stoppered flask containing the assay is placed upon an asbestos mat over a bunsen burner and boiled until solution is complete. It is then allowed to cool by placing the nozzle under sodium bicarbonate solution as before. When cool, the solution is titrated with standard $KMnO_4$ solution and FeO calculated in the usual manner.

EXPERIMENTS WITH KOH AND NaOH.

These substances were first tried on account of their low melting points, KOH being 360.4° C. and NaOH 318.4° C. Experiments were carried out by fusing tourmaline with them at temperatures of 600°-800° C. They, however, proved unsatisfactory owing to the rapidity with which they pick up water, rendering the mixing of the flux and mineral a difficult process. The presence of water in the mixture caused the mass to froth and the glass tubes to crack. No definite figures for FeO could be obtained.

EXPERIMENTS WITH ALKALI FLUORIDES.

The effect of fluorides was next tried as their action as a flux in ore magmas is well known.

Fluorides are stable salts to heat. J. Newton Friend (8) says, "Most fluorides are stable bodies not being decomposed by heating either alone or with carbon." Watt's Dictionary of Chemistry says, "Ferrous fluoride is unchanged by heat." J. Newton Friend (9) gives the volatilization temperature of ferrous fluoride as 1100° C. and ferric fluoride as 1000° C.

Melting points as given by various authorities:—

KF	...	789°C, 846°C, 859·9°C, and 867°C.
NaF	...	980°C, 986°C, and 988°C.
CaF_2	...	1360°C.

The effect of fusions with the lower M.P. fluorides and sinters with those of high M.Ps. was tried either alone or in mixtures by varying the temperature, time of heat treatment and the ratio of mineral to flux.

Potassium fluoride was first used on account of its low melting point. Experiments conducted by fusing both tourmaline and garnet at temperatures between 800°-900° C. proved unsatisfactory owing to the rapidity with which KF picks up water, and as in the case with the alkaline hydroxides no definite figures for FeO could be obtained.

Sodium fluoride was next tried. This substance does not pick up water as readily as the potassium salt and could be quite easily mixed with the

mineral. Experiments carried out by the foregoing method on samples of garnet and tourmaline gave the following results:—

Exp.	Garnet 459.	Flux NaF.	Temp.	Time.	FeO.	FeO.	FeO, HF H_2SO_4	Conditions.
					gms.	%	%	
23	·3	1·0	700—800°C	15′	·0318	10·6	19·1	Sinter.
24	·3	1·0	960—1000°C.	15′	·0512	17·1	...	Fusion.
	Tourmaline.							
28	·3	1·0	960—1040°C.	5′	·0273	9·1	14·5	Sinter.
29	·3	1·0	960—1040°C.	10′	·0307	10·2	...	Partial fusion.
30	·3	1·0	do.	10′	·0328	10·9	...	do.
31	·4	1·3	do.	10′	·0419	10·5	...	do.

Experiment 24 gave about 90 per cent. of the FeO obtained by the HF and H_2SO_4 method on garnet.

Experiment 30 gave about 75 per cent. of the FeO obtained by the HF and H_2SO_4 method on tourmaline.

Experiments 23 and 28 with sinters showed a small residue insoluble in sulphuric acid solution.

Experiments 24, 29-31 showed a small amount of fusion combined with the glass which was not completely soluble in sulphuric acid solution.

Generally speaking, the conditions and behaviour were much more satisfactory than those observed with the alkaline hydroxides and potassium fluoride. It was therefore decided to conduct more detailed investigations.

GARNET SAMPLE.

For subsequent experiments a sample of almandine garnet, Lab. No. 806, from Yabberup was prepared and analysed. This mineral was chosen on account of its refractoriness to hydrofluoric and sulphuric acids, although a figure for FeO can be obtained by the method used in this laboratory and described under the history of the methods. A microscopic examination of the residue after solution always revealed the presence of minute particles of undecomposed garnet, however finely the mineral was ground.

Analysis.

	%	
Al_2O_3	23·97	
Fe_2O_3	3·22	
*FeO	29·18	average of 4 results.
MnO	1·04	
CaO	3·44	
MgO	3·68	

* FeO determined by the H_2SO_4 and HF method on the finely ground garnet gave the following results:—

Exp. 32	29·94	FeO
,, 34	29·11	,,
,, 37	29·04	,,
,, 46	28·62	,,

A microscopic examination of the residue revealed the presence of minute particles of undecomposed garnet.

EXPERIMENTS WITH 10 : 1 MIXTURE NaF : GARNET.

Sodium fluoride prepared in the laboratory from sodium carbonate (BDH., AR.) and hydrofluoric acid (Baker's anal., C.P.) was used in these experiments.

Exp.	Garnet 806.	NaF.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
33	·3	3·0	960—1040°C.	10′	·0887	29·6	Fusion.
35	·4	4·0	do.	10′	·1132	28·3	Partial fusion. Combination with glass. Fusion not completely soluble.
36	·5	5·0	do.	10′	·1256	25·1	Fusion. Less soluble than 33 and 35.

The results indicate that, under certain conditions, garnet is decomposed without oxidation. In Exp. 33 the FeO content is only slightly lower than the highest result obtained in Exp. 32 by the HF and H_2SO_4 method.

Before proceeding with further experiments with sodium fluoride, the effect of mixtures of potassium acid fluoride and garnet in the ratio of 6 : 1 were tried.

Potassium acid fluoride when heated evolves HF and was tried to see if the HF generated would prevent oxidation by replacing the air in the tube.

EXPERIMENTS WITH 6 : 1 MIXTURE KHF_2 : GARNET.

Exp.	Garnet 806.	KHF_2	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
40	·5	3·0	960—1040°C.	15′	·0386	7·7	Partial fusion and combination with glass. Tube blown out.
41	·5	3·0	do.	20′	·0140	2·8	Complete fusion and combination with glass. Tube blown out.
42	·5	3·0	do.	25′	...	...	do. do.
43	·5	3·0	800°C.	20′	·0370	7·4	Sinter. Tube blown out.
44	·5	3·0	800—850°C.	60′	...	...	Complete fusion and combination with glass.

The HF liberated from the KHF_2 on heating caused the tubes to blow out. Higher temperatures with the lower M.P. of the potassium fluoride formed, caused excessive combination with the glass and incomplete solution of the fusion in sulphuric acid.

Experiments with NaF were continued by sintering at a temperature of 850°-960° C. (which is below the M.P. of NaF) with a 6 : 1 mixture of NaF : garnet, the NaF used being the pure reagent from F.G.B.

Experiments with 6 : 1 mixture of NaF pure : garnet.

Exp.	Garnet 806.	NaF F.G.B.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
47	·5	3·0	850—960°C.	25′	·0690	13·8	Sinter. Compact
48	·5	3·0	do.	25′	·0955	19·1	do. do.
49	·5	3·0	do.	60′	·0840	16·8	Undecomposed mineral.
50	·5	3·0	do.	30′	·0960	19·2	do. do.

In this series the disintegration and solution of the sinter was slow and incomplete.

Experiments with 10 : 1 mixture of NaF pure : garnet.

These experiments were carried out to see if the increased amount of NaF caused the sinters to disintegrate more readily upon boiling at the temperature used in Exp. 47-50.

Exp.	Garnet 806.	NaF F.G.B.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
52	·3	3·0	850—960°C.	30′	0·687	22·9	Black sinter. Not completely soluble.
53	·3	3·0	do.	60′	·0624	20·8	do. do.
54	·3	3·0	do.	30′	·0696	23·2	do. do.
55	·3	3·0	do.	20′	·0729	24·3	do. do.
56	·3	3·0	do.	15′	·0717	23·9	do. do.
57	·3	3·0	do.	10′	·0579	19·3	Not sintered properly. Undecomposed mineral.
58	·3	3·0	do.	10′	·0495	16·5	do. do.
59	·3	3·0	do.	15′	·0666	22·2	Black sinter not completely soluble.
63	·3	3·0	960—1040°C	10′	·0669	22·3	do. do.

The 10:1 mixtures sinter well and disintegrate more readily than the 6:1 mixtures but are still incompletely soluble.

The best conditions obtained were those by heating at 850-960° C. for 15 minutes, or 960-1040° C. for 10 minutes. The glass was not appreciably attacked.

The low results obtained are due to either –

(a) Incomplete decomposition of the garnet, or

(b) Oxidation of the FeO during experiment.

Experiment 71 was carried out to see if any oxidation took place in boiling a solution of NaF with H_2SO_4 and B_2O_3 solution.

Control Experiment.

Exp. 71.—.1018 grm. Standard Steel (99.64 per cent. Fe) was dissolved in 30 ccs. 10E H_2SO_4 and made up to 200 ccs. with freshly boiled water in a 250 cc. stoppered flask. 1.0 gms. NaF and 1.0 gms. B_2O_3 were

then added and the whole boiled for 15 minutes. This solution was cooled and treated as in the previous experiments. .1018 gms. Standard steel (99.64 per cent. Fe) added = .1014 Fe, Exp. 71 = .1006.

This experiment shows that no appreciable oxidation takes place in the final stage of the operation.

Experiments were next carried out by introducing varying amounts of KHF_2 with the NaF (F.G.B.), still adhering to the 10 : 1 mixture of flux and garnet. The KHF_2[10] was added to generate HF during the heating stage to displace the air and prevent oxidation from this source. A small vent was left at the top of tube to allow the HF to escape.

EXPERIMENTS WITH 10 : 1 MIXTURE OF NaF, KHF_2 : GARNET.

Exp.	Garnet 806.	NaF F.G.B.	KHF_2	Temp.	Time.	FeO.	FeO.	Conditions.
						gms.	%	
62	·3	2·7	·3	850—960°C.	15′	·0624	20·8	Sinter same as with NaF alone. Yellow solution.
64	·3	2·5	·5	960—1040°C.	5′	·0375	12·5	do.
65	·3	2·5	·5	do.	10′	·0429	14·3	Fusion; combination with glass. Yellow solution.
66	·3	2·0	1·0	do.	5′	·0279	9·3	do.

The introduction of the KHF_2 did not have the desired effect as the FeO figure obtained in all cases was low. The yellow colour of the solutions indicates that oxidation has occurred. The best conditions and highest results have been obtained with sodium fluoride alone.

The pure NaF (F.G.B.) used in the previous experiments has a pH value of 4.2 to Brom-cresol green. The KHF_2 used has a pH value of 2.4 to Thymol blue. There is therefore the possibility of some acid fluoride being present in the NaF. Three experiments were next carried out with NaF (F.G.B.) heated to 850-960° C. to drive off any HF and convert the $NaHF_2$ to NaF.

EXPERIMENTS WITH 10 : 1 MIXTURE NaF : GARNET.

Exp.	Garnet 806.	NaF (F.G.B.) 850—960°.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
68	·3	3·0	960—1040°C.	10′	·0597	19·9	Sinter—partial fusion.
69	·3	3·0	850—960°C.	15′	·0639	21·3	do. do.
70	·3	3·0	do.	15′	·0639	21·3	do. do.

The sintering with NaF (F.G.B.) heated to 850-960° C. did not give any better results than when sintered with original NaF (F.G.B.).

SODIUM FLUORIDE (F.G.B. PURE).

Experiments were carried out on this material to test its purity.

Effervescence takes place with 5EHCl, and not with NaF prepared in the laboratory.

The pH value—4.2—is well on the acid side for neutral NaF.

Analysis ...	Na_2O	71·6 %
	Na	52·8 %
	F	44·20 %
NaF contains theoretically		
	Na	54·76 %
	F	45·24 %

These tests show that some $NaHF_2$ is present in this material.

Sodium fluoride neutral was prepared in the laboratory by neutralising NaOH (BDH., AR) with HF (Baker's Anal. C.P.) using litmus papers as indicators.

EXPERIMENTS WITH 10 : 1 MIXTURE NaF : GARNET.

Exp.	Garnet 806.	NaF (Lab.).	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
72	·3	3·0	960 1040°C.	10′	·0846	28·2	Sinter—part fusion. Little combination with glass.

The results upon garnet No. 806 obtained from the foregoing show that only three experiments have given figures for FeO which are anyway near the figures obtained by the HF and H_2SO_4 methods—29.18 per cent. FeO. They are two preliminary experiments, 33 and 35, and the last experiment 72.

Exp. 33 ...	29·56 %	FeO
„ 35 ...	28·30 %	„
„ 72 ...	28·20 %	„

These three experiments were carried out upon sodium fluoride prepared in the laboratory from analytical reagents. The first two were prepared from Na_2CO_3 (BDH., AR.) and HF (Baker's Anal. C.P.) and the last from NaOH (BDH., AR) and HF (Baker's Anal. C.P.).

The experiments carried out with NaF (F.G.B.) alone gave figures ranging from 66.83 per cent. of the FeO obtained by HF and H_2SO_4 method. These figures show that a large proportion of the FeO can be determined and in the case of the neutral NaF prepared in the laboratory nearly the whole of it. It was therefore decided to prepare—

1. Pure neutral NaF from NaOH (BDH., AR) and HF (Baker's Anal. C.P.).
2. $NaHF_2$ from the above neutral NaF and HF (Baker's Anal. C.P.).
3. Pure neutral KF from KOH (BDH., AR) and HF (Baker's Anal. C.P.).
4. Pure CaF_2 from $CaCO_3$ (BDH., AR.) and HF (Baker's Anal. C.P.).

and to carry out experiments on these pure compounds, both alone and in mixtures, still adhering to the 10 : 1 flux mineral mixture.

PREPARATION OF PURE NEUTRAL SODIUM FLUORIDE.

A solution of NaOH (BDH., AR) was neutralised by careful addition of diluted HF (Baker's Anal. C.P.) until a pH value of 7.0 was obtained with Brom-thymol Blue: a spotting tile was used for this indicator. The solution containing separated NaF was evaporated to dryness on a water bath, finished off on a sand bath at a temperature of about 250° C.

The pH value of the solution had not altered on being heated to temperature of sand bath.

EXPERIMENTS WITH 10 : 1 MIXTURE NaF : GARNET.

Exp.	Garnet 806.	NaF Neutral 250°C.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
77	·3	3·0	850—960°C.	15′	·0639	21·3	Black sinter showing partial fusion and combination with glass.
86	·3	3·0	do.	15′	·0801	26·7	Black sinter; no combination with glass. Some mineral unattacked.

In Exp. 86 the NaF neutral was calcined at 600° C.

Consideration was given to the possibility of platinum being present, causing oxidation by catalysis upon heating.

Sodium fluoride neutral was prepared in silica ware only and comparative experiments run with sodium fluoride neutral prepared in platinum ware with the following results.

EXPERIMENTS WITH 10 : 1 MIXTURE NaF : GARNET.

Exp.	Garnet 806.	NaF Neutral 600°C.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
87	·3	3·0	850—960°C.	25′	·0828	27·6	NaF prepared in SiO_2 ware. All material carefully dried. Sinter similar to Exp. 86. Some mineral unattacked.
88	·3	3·0	850—960°C.	20′	·0849	28·3	NaF prepared in Pt. ware. Conditions as in Exp. 87.
91	·3	3·0	960—1040°C	15′	·0375	12·5	Fusion and combination with glass.

These results show that the use of platinum ware for the preparation of the sodium fluoride is not harmful.

In these experiments unattacked garnet was observed.

Experiments with a view to obtaining complete attack upon the garnet by either increasing the temperature or increasing the length of time of heat treatment were carried out, and all materials were dried before mixing and sealing.

EXPERIMENTS WITH 10 : 1 MIXTURE NaF : GARNET.

Exp.	Garnet 806.	NaF 600°C.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
93	·3	3·0	1040—1150°C.	15′	·0246	8·2	All material dried. Fusion and combination with glass. All mineral attacked. Some fusion undissolved.
98	·3	3·0	850—960°C.	45′	·0354	11·8	All material dried. Sinter. Some unattacked mineral.

Increase in temperature to 1040-1150° C. caused decomposition of the mineral but combination with glass, which being difficultly soluble, caused low results for FeO.

Longer heat treatment at temperature of 850-960° C. did not completely decompose the mineral.

It was decided to repeat Exps. 87 and 88 for verification and further information.

Repetition of Exps. 87 *and* 88. Sintering with dried and undried sodium fluoride with garnet.

EXPERIMENTS WITH 10 : 1 MIXTURE NaF : GARNET.

Exp.	Garnet 806.	NaF 600°C.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
102	·3	3·0	850—960°C.	20′	·0828	27·6	NaF dried. Mineral not completely decomposed.
103	·3	3·0	do.	20′	·0828	27·6	NaF not dried. Mineral not completely decomposed.

These results verify the results obtained in Exps. 87 and 88 and prove *that sintering with neutral sodium fluoride at temperature of 850-960° C. does not completely decompose the garnet.* There does not appear to be any necessity to dry the mixture before sealing and heating.

As a result of the experiments carried out on sodium fluoride alone, it was decided to carry out experiments by introducing a lower M.P. substance into the mixture of sodium fluoride and garnet in an attempt to lower the M.P. of the mixture and so obtain fusions at the temperature of 850-960° C. without combination with the glass.

EXPERIMENTS WITH 10 : 1 MIXTURE OF NaF, NaOH : GARNET.

Exp.	Garnet 806.	NaF 600°C.	NaOH.	Temp.	Time.	FeO.	FeO.	Conditions.
						gms.	%	
83	·3	2·5	·5	850—960°C.	10′	·0564	18·8	Sinter. Some mineral unattacked.
85	·3	2·5	·5	do.	18′	·0549	18·3	do. do.
82	·3	1·5	1·5	do.	8′	·0270	9·0	Fusion and partial combination with glass.
84	·3	1·5	1·5	do.	5′	·0153	5·1	Semi-fusion reddish in colour showing oxidation of the FeO. Combined with glass.

The deliquescent nature of the NaOH made the mixing of the flux with the mineral a difficult operation. The presence of the water introduced with the NaOH must be considered as a possible source of oxidation of FeO.

J. Newton Friend in "The Text Book of Inorganic Chemistry," Vol. II., p. 148, gives two equations showing the liberation of chlorine on heating with SiO_2 in presence of H_2O and O up to 1000° C.

$$2x\mathrm{NaCl} + y\mathrm{SiO_2} + x\mathrm{H_2O} = x\mathrm{Na_2O}.y\mathrm{SiO_2} + 2x\mathrm{HCl}. \quad 4\mathrm{HCl} + \mathrm{O_2} = 2\mathrm{H_2O} + 2\mathrm{Cl_2}$$

If this occurs there is the possibility of the liberation of fluorine under the similar conditions with a consequent oxidation of the FeF_2.

As a result of the above experiments the introduction of NaOH into the flux was discontinued.

Experiments with KF prepared in the laboratory alone and mixed with NaF (600° C.) were carried out for the reasons outlined under the experiments carried out with NaOH.

PREPARATION OF PURE NEUTRAL POTASSIUM FLUORIDE.

A solution of KOH (BDH., AR) was neutralised with HF (Baker's Anal. C.P.) to a pH value of 7.0 with Brom Thymol Blue in a similar manner to the preparation of the sodium fluoride. It was evaporated to dryness upon a water bath and calcined at a temperature of 600° C. After calcining, the KF was found to be of uneven composition, some pieces being quite alkaline and others reacting acid. Heat was evolved when the calcined KF was dissolved in water, the solution reacting alkaline. Dissociation had taken place according to the equation $2KF + H_2O \longrightarrow K_2O + 2HF$. Experiments taken of the pH value of the $KF.2H_2O$ formed by evaporating upon water bath and heating at various temperatures were carried out:—

100°C. ...	pH 6·8
130°C. ...	... 6·8
200°C. ...	... 6·8
600°C. ...	... 7·0

The 600° C. product when heated in the closed tube showed only a trace of water.

EXPERIMENTS WITH 10 : 1 MIXTURE OF KF (600° C.) : GARNET.

Exp.	Garnet 806.	KF 600°C.	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
90	·3	3·0	850—960°C.	10′	·0807	26·9	Partial fusion. Combination with glass. Fusion not completely soluble.

The KF, owing to its deliquescent nature, was dried on sand bath, mixed with garnet, and sealed quickly. Water was picked up before the operation could be completed.

EXPERIMENTS WITH 10 : 1 MIXTURE OF NaF AND KF : GARNET.

Exp.	Garnet 806.	NaF 600°C.	KF 600°C.	Temp.	Time.	FeO	FeO.	Conditions.
						gms.	%	
92	·3	2·5	·5	850—960°C.	15′	·0744	24·8	Partial fusion. Yellow solution.
94	·3	2·5	·5	do.	15′	·0807	26·9	Mixture in tube dried at 100° for 1 hour. Partial fusion. Yellow solution.
96	·3	2·5	·5	do.	15′	·0549	18·3	do. do.
104	·3	2·5	·5	do.	15′	·0786	26·2	Mixture carefully dried at 130°C. Sinter partial fusion. Yellow solution.
105	·3	2·5	·5	do.	15′	·0783	26·1	No drying precautions. Sinter—partial fusion. Yellow solution.
106	·3	2·0	1·0	do.	15′	·0846	28·2	More fusion than in Exp. 92, 94, 104, 105. Similar to Exp. 108.
108	·3	2·0	1·0	800°C.	15′	·0870	29·0	Sinter—little fusion. Pale yellow solution. All mineral apparently attacked.
109	·3	2·0	1·0	850 960°C.	15′	·0822	27·4	More fusion than in Exp. 106 due to higher temp. Combination with glass. All mineral apparently attacked.
111	·3	2·0	1·0	under 800°C.	15′	·0870	29·0	Similar conditions to Exp. 108. All mineral attacked.

Exp's. 92 96. All tubes and reagents dried before filling and sealing.

These experiments did not give any higher results than those obtained with the NaF alone. The presence of KF lowered the M.P. of the mixture, giving partial fusions and more complete decomposition of the mineral. The yellow colour of the solutions indicates some oxidation of the FeO.

Exp's. 106, 108, 109, 111. with a mixture of 2.0 grms. NaF and 1.0 grm. KF gave consistently higher results than those obtained with NaF

alone. The increased amount of KF resulted in more complete fusions and, at temperatures of about 800° C., very little combination with glass took place, with apparent complete decomposition of the garnet. Further experiments were carried out to confirm these results.

EXPERIMENTS WITH 10 : 1 MIXTURE OF KF, NaF : GARNET.

Exp.	Garnet 806.	NaF 600°C.	KF 600°C.	Temp.	Time.	FeO.	FeO.	Conditions.
						gms.	%	
112	·3	2·0	1·0	800°C	15′	·0837	27·9	Similar conditions to Exp. 111. Mineral unattacked. Pale yellow solution.
113	·3	2·0	1·0	850°C	15′	·0786	26·2	More fusion than in Exp. 112. Yellow solution.
114	·3	2·0	1·0	700–800°C.	15′	·0786	26·2	Sinter. Very little fusion.

Whilst the high figures of Exps. 106, 108, 109, and 111 are not confirmed, improved conditions of the partial fusion, with very little combination with the glass at temperatures at 800° C. were obtained. There appears to be a little oxidation of the FeO when the colour of the solution is taken into consideration.

The deliquescent nature of the KF renders the materials hard to mix.

Further experiments were carried out in repetition of the above with the following results:—

EXPERIMENTS WITH 10 : 1 MIXTURE OF KF, NaF : GARNET.

Exp.	Garnet 806.	NaF 600°C.	KF 600°C.	Temp.	Time.	FeO.	FeO.	Conditions.
						gms.	%	
161	·3	2·0	1·0	800–850°C.	15′	·0765	25·5	Dried 2 hours, mixed and sealed while hot. Partial fusion. Yellow solution.
163	·3	2·0	1·0	800°C.	15′	·0660	22·0	Sinter-fusion, reddish at top due to oxidation. Yellow solution.
164	·3	2·0	1·0	700°C.	15′	·0432	14·4	Sinter. Some unattacked mineral.
165	·3	2·0	1·0	800°C.	15′	·0699	23·3	Sinter—fusion. Yellow solution.

These figures do not confirm the highest results obtained in Exps. 106, 108, 109, 111. The yellow solution denotes oxidation of the FeO.

The experiments carried out with mixtures of sodium fluoride, and the lower melting point potassium fluoride not proving satisfactory, experiments were next conducted by introducing the higher melting point calcium

fluoride into the sodium fluoride garnet mixture to see if the garnet could be decomposed without oxidation and combination with the glass by sintering.

Experiments were first carried out using NaF prepared in the laboratory and CaF_2 (pure Kahlbaum).

Experiments with 10 : 1 mixture NaF, CaF_2 : garnet.

Exp.	Garnet 806.	NaF 600°C.	CaF_2 Kahlbaum.	Temp.	Time.	FeO.	FeO.	Conditions.
						gms.	%	
121	·3	2·5	·5	960—1040°C.	15′	·0780	26·0	Partial fusion. Combination with glass. Incomplete solubility.
122	·3	2·5	·5	850 960°C.	15′	·0885	29·5	Hard black sinter. No combination with glass. Black scum on solution.
123	·3	2·5	·5	850—960°C.	15′	·0885	29·5	do. do.
124	·3	2·0	1·0	do.	15′	·0732	24·4	Hard black sinter. Disintegrates with difficulty.

Kahlbaum's CaF_2 on examination was found to contain paraffin, probably from the stopper; this accounted for the black scum noticed in Exp. 124.

Experiment 121 at the higher temperature of 960-1040° C. partly combined with the glass, whilst Exp. 124 with the increased amount of CaF_2 gave a hard sinter which did not completely disintegrate on boiling. An experiment was therefore carried out under conditions pertaining to Exp. 122, and 123 with CaF_2 prepared in the laboratory from $CaCO_3$ (BDH., A.R.) and HF (Baker's Anal. C.P.).

Experiments with 10 : 1 mixture NaF, CaF_2 : garnet.

Exp.	Garnet 806.	NaF 600°C.	CaF_2 Lab.	Temp.	Time.	FeO.	FeO.	Conditions.
						gms.	%	
125	·3	2·5	·5	850—960°C.	15′	·0807	26·9	Sinter similar to Exp. 121—123. No black scum.

This experiment, in the absence of organic material, gave a lower result than Exps. 122 and 123.

Experiments were carried out introducing sufficient carbon to reduce all the iron present calculated as Fe_2O_3 to FeO.

EXPERIMENTS WITH 10 : 1 MIXTURE OF NaF, CaF_2: GARNET WITH CARBON.

Exp.	Garnet 806.	NaF 600°C.	CaF_2 Lab.	C.	Temp.	Time.	FeO.	FeO.	Conditions.
							gms.	%	
126	·3	2·5	·5	·05, 850	960°C.	15′	·0906	30·2	Sinter similar to Exps. 122, 123 and 125.
127	·3	2·5	·5	·007	do.	15′	·0894	29·8	do. do.

The FeO figure obtained in Exp. 126 calculated to Fe_2O_3 is 33.5 per cent. The total iron in the sample calculated to Fe_2O_3 is 35.6 per cent. This figure should be obtained if the mineral is completely decomposed.

To ascertain whether the whole of the garnet had been decomposed, further experiments were run under similar conditions to Exps. 126, 127, with a microscopic examination of any residue after solution of the fusion.

EXPERIMENTS WITH 10 : 1 MIXTURE OF NaF, CaF_2: GARNET WITH CARBON.

Exp.	Garnet 806.	NaF 600°C.	CaF_2 Lab.	C.	Temp.	Time.	FeO.	FeO.	Conditions.
							gms.	%	
157	·3	2·5	·5	·01	900°C.	15′	·0897	29·9	Hard stone-like sinter. No combination with glass. Undecomposed garnet.
158	·3	2·5	·5	·01	900°C.	20′	·0801	26·7	More vesicular than Exp. 157. Partial combination with glass.
152	·3	2·5	·5	·007	700–800°C.	60′	·0876	29·2	Similar to Exp. 157. Undecomposed garnet.
154	·3	2·5	·5	·007	800°C.	60′	·0825	27·5	do. do.
155	·3	2·5	·5	·007	850°C.	60′	·0828	27·6	More vesicular than Exp. 154. Undecomposed garnet.
156	·3	2·5	·5	·007	900°C.	60′	·0831	27·7	do. do.

A microscopic examination revealed the presence of undecomposed garnet grains. This confirmed the opinion formed as a result of the previous experiments—that the low FeO figure is due to this cause.

Discussion.

A review of the experiments using the 10 : 1 mixture of NaF : garnet at varying temperatures and times showed that—

1. The best conditions were obtained by sintering at temperatures of 850-960° C. for a period of 15 to 20 minutes, the FeO results varying from 21.3 to 28.32 per cent. These inconsistent results were due mainly to varying amounts of undecomposed mineral, noticed in most of these experiments.

2. Partial fusions were obtained by heating at temperatures of 960-1040° C. for 10 to 15 minutes, the FeO results varying from 12.54 to

29.6 per cent. These inconsistent results are due both to small amounts of undecomposed mineral and combination with the glass to a variable extent. The melting point of NaF is 980° C., which lies between the extreme ranges of temperature at which these experiments were conducted.

3. Complete fusions were obtained at temperatures between 1040° and 1150° C. by heating over a period of 15 minutes with excessive combination with the glass, giving the low result for FeO of 8.25 per cent. The mineral was completely attacked in this case.

As a result of these experiments with NaF alone it was concluded that whilst complete decomposition of the garnet can be obtained at temperatures above 980° C., the melting point of the NaF, the combination with the glass precluded the possibility of accurate results being obtained. Also by sintering at lower temperatures than 980° C. the garnet was not completely decomposed.

The results obtained by heating garnet with KF and mixtures of KF and NaF in the proportion of 10 parts of flux to one of mineral at varying temperatures showed that—

The best conditions were obtained by heating 10 : 1 mixtures of flux : garnet at a temperature of 800° C. for 15 minutes when the proportion of NaF.KF was 2 : 1 and 850-960° C. when the proportion was 5 : 1. The former gave results varying from 14.4 to 29.0 per cent. FeO and 18.3 to 26.2 per cent. FeO in the latter. Under these conditions complete decomposition of the garnet was obtained with very little combination with the glass. The temperature required controlling carefully as an appreciable rise caused increased combination with the glass.

Why these low and inconsistent results should be obtained is not definitely known, but it is possible that they may be caused by the introduction of water from the hygroscopic KF whilst mixing. See page 183 re behaviour of KF on calcining at 600° C. and equations showing reaction on heating NaCl, SiO_2 and water.

The results obtained with 6 : 1 mixture of KHF_2 : garnet were altogether unsatisfactory as the liberation of HF caused the tubes to blow out, and the low melting point of the KHF_2 caused excessive combination with the glass. The FeO results varied from nil to 7.7 per cent.

With mixtures of NaF and KHF_2 in the proportion of 9 : 1 and the flux : garnet ratio of 10 : 1 results varying from 9.3 to 20.8 per cent. FeO were obtained by heating at temperatures of 850°-1040° C. In all cases the yellow solution indicated oxidation of FeO.

When CaF_2 was introduced into the NaF : garnet mixture, the best conditions were obtained by heating 10 : 1 mixtures of flux : garnet at temperatures of 850°-960° C. for 15 minutes when the proportion of CaF_2 : NaF was 1 : 5. Experiment 125, the only one without carbon, gave a figure of 26.9 per cent. FeO. Experiments 152, 154-8 showed that under these conditions garnet was incompletely decomposed. An increase in temperature to 960°-1040° C. caused combination with the glass, and the increased ratio of CaF_2 : NaF of 1 : 2 at temperatures of 850°-960° C., gave a sinter which did not disintegrate completely.

EXPERIMENTS WITH SODIUM PYROBORATE.

The effect of sodium pyroborate upon the decomposition of the garnet was next tried as it was considered there would be very little action upon the glass on account of its low melting point and acidity as a flux.

Melting point 561° C., 734° C., 741° C., 878° C.

GARNET SAMPLE.

The sample of garnet, Lab. No. 806, being exhausted, a further sample, Lab. No. 735/32 from the same district, Yabberup, was prepared, analysed, and used in the subsequent investigations.

Analysis, 735/32.

	%
SiO_2	35·29
Al_2O_3	19·25
Fe_2O_3	3·31
*FeO	30·30
MnO	1·47
CaO	3·50
MgO	3·36
H_2O	·62
H_2O—	*Nil*
TiO_2	3·14
Total	100·24

*By HF and H_2SO_4 method.

EXPERIMENT WITH 5 : 1 MIXTURE OF $Na_2B_4O_7$: GARNET.

Exp.	Garnet 735/32.	$Na_2B_4O_7$	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
171	·3	1·5	850–960°C.	15′	·0732	24·4	Dark bottle green fusion. No combination with glass. Undecomposed garnet.
172	·3	1·5	do.	30′	·0765	25·5	Dark bottle green fusion. No combination with glass. Undecomposed garnet. Yellow solution.
173	·3	1·5	do.	30′	·0789	26·3	do. do.
174	·3	1·5	do.	45′	·0801	26·7	do. do.
175	·3	1·5	do.	60′	·0768	25·6	do. do.

These experiments showed that fusions with $Na_2B_4O_7$ whilst not exhibiting any appreciable attack upon the glass, dissolved in H_2SO_4 to a yellow solution, leaving a residue of undecomposed garnet.

Experiments mixing NaF with $Na_2B_4O_7$ were next carried out in an attempt to completely decompose the garnet without excessive combination with the glass.

It was found impossible to mix the fluxes without the introduction of water into the tubes owing to the rate at which anhydrous boric acid picks it up. Further experiments were all rejected owing to the difficulty in controlling the fusions.

The effect of fusing together NaF and B_2O_3 before mixing with the garnet was next tried and an investigation of the constitution of this product undertaken.

Notes on the Properties of Fluoboric Acid and Fluoborates.

Berzelius[14] says that HF and Boric acid together give $H_2B_2O_4.6HF$. This is thought to be a mixture of metaboric acid, hydrofluoboric acid, and HF.

Abegg, Fox and Henry[15] tried reactions between Boric acid, HF and KF with no definite conclusion.

Friend[15] says, "Although no fluoboric acids are definitely known, two compounds have been formed which may be looked upon as salts of such acids." They are:—

$$B_2O_3.(KF)_2$$
$$(B_2O_3).(KF)_2.K_2O$$

The first of these is formed by fusing together two molecular proportions of KF with one of B_2O_3 and allowing the melt to cool slowly.

The second by fusing the former with the requisite amount of K_2CO_3.

These compounds dissolve, without decomposition, in a little water, but with much water they decompose.

Mellor[16] says, "Most of our knowledge of the fluoborates is still in the state left by Berzelius."

Preparation of Sodium Fluoborates.

To decide the proportions of B_2O_3 and NaF to be fused together to form sodium fluoborates, consideration was first given to the known Boric acids and Borates and the possible fluoborates formed from them by substituting 2NaF for Na_2O.

The known Boric acids[17] are:—

1. Orthoboric acid $(H_2O)_3.B_2O_3$.
2. Metaboric acid $H_2O.B_2O_3$.
3. Pyro or tetraboric acid $H_2O.(B_2O_3)_2$. This acid is assumed by chemists. Its Sodium salt, Borax, is well known.

The sodium salts[18] of these acids are:—

1. Sodium orthoborate $(Na_2O)_3.B_2O_3$. There are very few orthoborates known.
2. Sodium metaborate $Na_2O.B_2O_3$.
3. Sodium pyro or tetraborate $Na_2O.(B_2O_3)_2$.

The possible fluoborates analogous with these borates are:—

1. Sodium orthofluoborate $(NaF)_6.B_2O_3$.
2. Sodium metafluoborate $(NaF)_2B_2O_3$. The potassium salt of this constitution is referred to by Friend and recorded above.
3. Sodium pyrofluoborate $NaF.B_2O_3$.

As the sodium metaborate has been prepared and the potassium salt of metafluoboric acid has been referred to, it was decided to attempt to prepare sodium metafluoborate by fusing together 2 molecular proportions of NaF and 1 of B_2O_3 in a platinum dish at temperatures of about 1000° C. (this is above the M.P. of NaF) and to carry out experiments with this product. This fused product was ground and sieved so that it could be mixed with the garnet.

EXPERIMENTS WITH 5 : 1 MIXTURE SODIUM METAFLUOBORATE : GARNET.

Exp.	Garnet 735/32.	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
187	·5	2·5	600—700°C.	30′	·1485	29·7	Silver grey vesicular sinter. No bubbling or swelling. Dark coloured flocculent residue.
189	·5	2·5	600—700°C.	30′	·1465	29·3	do. do
191	·3	1·5	700—800°C.	30′	·0918	30·6	do. do.
192	·4	2·0	do.	30′	·1188	29·7	do. do.
195	·4	2·0	do.	30′	·1204	30·1	do. do.
206	·4	2·0	do.	30′	·1204	30·1	do. do.

The dark coloured flocculent residue noticed in these experiments indicated the presence of carbonaceous material which would give high and erroneous results for FeO.

The following reagents were tested for carbon by dissolving in water and fuming with sulphuric acid:—

Boric acid (B.D.H., B.P.), Carbon present.
„ „ (B.D.H., A.R.), Carbon absent.
Sodium fluoride (Lab.), Carbon absent.

Carbon free sodium fluoborate was prepared by fusing together two molecular parts of NaF (prepared in the laboratory and calcined at 600° C.) and one part of anhydrous B_2O_3 glass (prepared from Boric acid (B.D.H., A.R.) in an electric furnace at temperature of about 1000° C. This fused product was ground in diamond and agate mortars without sieving.

EXPERIMENTS WITH 5 : 1 MIXTURE SODIUM METAFLUOBORATE (CARBON FREE) : GARNET.

Exp.	Garnet 735/32.	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
206	·4	2·0	700—800°C.	30′	·1188	29·7	Silver grey vesicular partial fusion. No dark-coloured residue.
207	·4	2·0	700—800°C.	30′	·1280	32·0	More fusion than Exp. 206. Small amount of carbonaceous material. Discard.
208	·4	2·0	700—800°C.	30′	·1204	30·1	Less fusion than Exp. 207. No carbonaceous material.
209	·4	2·0	700—800°C.	30′	·1284	32·1	Similar to 208.

The FeO figures in Experiments 206 and 208 are close to the figure obtained by the HF and H_2SO_4 method, 30.3 per cent. FeO. Experiments 207 and 209 gave higher results, the latter being free from carbonaceous material.

A further series of experiments were carried out with carbon free sodium metafluoborate and garnet crushed to pass -90 mesh only with no further fine grinding.

EXPERIMENTS WITH 5 : 1 MIXTURE SODIUM METAFLUOBORATE (CARBON FREE) : GARNET—90 MESH.

Exp.	Garnet 735 32. —90 mesh.	$(NaF)_2B_2O_3$	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
210	·5	2·5	700—800°C.	30′	·1565	31·3	Similar to Exp. 209.
211	·5	2·5	do.	30′	·1565	31·3	do. do.
212	·5	2·5	—700°C.	30′	...	...	Incomplete decomposition of garnet.
213	·5	2·5	700 800°C.	30′	·1505	30·1	Partial fusion. Incomplete decomposition of garnet.

Experiments 206-213 carried out with carbon free sodium metafluoborate gave FeO figures varying from 29.7 per cent. to 32.1 per cent. Experiment 213 with -90 mesh garnet at temperatures of 700-800° C. showed undecomposed garnet grains in the residue and an FeO figure of 30.1 per cent. These figures are higher and more consistent than the figures obtained with the fluxes previously tried.

Experiments 214-225 were carried out at increased temperatures of 800 to 960° C. for varying times with -90 mesh garnet in an attempt to obtain complete decomposition of garnet.

EXPERIMENT WITH 5 : 1 MIXTURE $(NaF)_2.B_2O_3$: GARNET.

Exp.	Garnet 735 32.	$(NaF)_2B_2O_3$	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
214	·4	2·0	800—850°C.	20′	·1276	31·91	Silver grey vesicular fusion. No carbonaceous material. Fusion completely soluble.
218	·4	2·0	800 900°C.	20′	·1259	31·47	Similar to Exp. 214.

The best conditions were observed in Experiments 214 and 218, and the FeO figures were higher than those obtained by the HF and H_2SO_4 method, 30.30 per cent. Experiment 219 was carried out to see if $(NaF)_2.B_2O_3$ had any action upon $KMnO_4$.

CONTROL EXPERIMENT.

Exp. 219.—1.5 grm. $(NaF)_2.B_2O_3$ was added to the dilute sulphuric acid solution, boiled, cooled under sodium bicarbonate seal as in the method and titrated with standard $KMnO_4$ solution. One drop of $KMnO_4$ solution gave faint pink colour, therefore no action has taken place causing the higher results.

Experiment with 5 : 1 mixture $(NaF)_2.B_2O_3$: garnet.

Exp.	Garnet 735/32. —90 mesh.	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
220	·5	2·5	850 –960°C.	25′	·1559	31·19	Silver grey compact fusion. Complete solution.
	Fine						
221	·4	2·0	do.	20′	·1241	31·03	do. do.
222	·4	2·0	do.	20′	·1248	31·21	Silver grey compact fusion. Complete solution. Slight combination with glass.
223	·5	2·5	900°C.	20′	·1580	31·60	Vesicular fusion. Complete solution.
	—90						
224	·4	2·0	900 –960°C.	20′	·1262	31·56	Silver grey fusion. Complete solution.
225	·4	2·0	do.	20′	·1276	31·91	Similar to Exp. 224.

Experiments 220, 224-5 on –90 mesh garnet at temperatures between 850-960° C. gave FeO figures varying from 31.19-31.91 per cent. Experiments 221-223 on the finely ground garnet at similar temperatures gave FeO figures varying from 31.03-31.60 per cent. There is no necessity therefore to fine grind the garnet.

The best conditions were observed in Experiments 224-225 by fusing for 20 minutes at temperatures of 900-960° C. and confirm the previous best conditions observed in Experiments 214 and 218.

The FeO figure by the HF and H_2SO_4 method is 30.30 per cent. and a microscopic examination of the residue revealed grains of undecomposed garnet. The total iron figure calculated to FeO gives 33.48 per cent. FeO. The best figures obtained by fusion with $(NaF)_2.B_2O_3$ lie between these. Therefore the results obtained in series 220-225 must be considered satisfactory as they are the highest and most consistent figures yet obtained and justify further investigation.

The mean FeO value obtained by the fluoborate method at temperatures over 900° C. (Exp's. 223-5) is 31.69 per cent. FeO. This figure is verified when it is applied to the constitution of the garnet described in Part I. of the Paper.

CONSTITUTION OF THE FLUOBORATES.

At this stage it was decided to analyse the sodium metafluoborate used in Experiments 224-5 and to prepare and analyse for further experiments:

1. *Sodium metafluoborate* $(NaF)_2.B_2O_3$, Batch 239—by heating 6.03 gms. NaF (Lab) with 5.00 gms. B_2O_3 (prepared from Boric acid BDH., AR.) at 1000° C. until completely miscible.

2. *Sodium pyrofluoborate $NaF.B_2O_3$, Batch* 240—by heating 3.01 gms. NaF (Lab.) with 5.00 gms. B_2O_3 (BDH., AR.) at 1000° C. until completely miscible.

ANALYSIS OF $(NaF)_2.B_2O_3$ USED IN EXPERIMENTS 224-225.

	Anal.	Theoretical.
	%	%
F	16·17	24·73
Na	31·38	29·94
B_2O_3	...	45·33

ANALYSIS $(NaF)_2.B_2O_3$, BATCH 239.

	Anal.	Theoretical.
	%	%
F	18·75	24·73
Na	31·05	29·94
B_2O_3	45·62	45·33
	95·42	100·00

By Calculation.

	Anal.		NaF.		Na_2O.	B_2O_3	Total.
	%		%		%	%	%
F	18·75		18·75		...	...	18·75
Na	31·05		22·70		...	...	22·70
Na_2O		41·85		30·60	11·25	...	11·25
B_2O_3	45·62		...		...	45·62	45·62
Total ...	95·42		41·45		11·25	45·62	98·32

		$(NaF)_2.B_2O_3$	$Na_2O.B_2O_3$	Total.
	%	%	%	%
NaF	41·45	41·45	...	41·45
Na_2O	11·25	...	11·25	11·25
B_2O_3	45·62	34·36	12·64	47·00
Total ...	98·32	75·81	23·89	99·70

Possible Composition.

Sodium metafluoborate $(NaF)_2.B_2O_3$	75·81
,, metaborate $Na_2O.B_2O_3$	23·89
Total	99·70

The higher figure for B_2O_3, 47.00 per cent., obtained by calculation and the corresponding high total of 99.70 per cent. indicates a loss of B_2O_3 in the determination. c.f. Analysis of sodium pyrofluoborate, Batch 240.

ANALYSIS OF $NaF.B_2O_3$, BATCH 240.

	Anal.	Theoretical.
	%	%
F	8·95	17·02
Na	21·61	20·60
B_2O_3	65·20	62·38
	95·76	100·00

By Calculation.

	Anal.		NaF.		Na_2O.	B_2O_3	Total.
	%		%		%	%	%
F	8·95		8·95		...	...	8·95
Na	21·61		10·83		...	...	10·83
Na_2O		29·13		14·60	14·53	...	14·53
B_2O_3	65·20		...		...	65·20	65·20
Total ...	95·76		19·78		14·53	65·20	99·51

		$NaF.B_2O_3$	$Na_2O\ (B_2O_3)_2$	Total.
	%	%	%	%
NaF	19·78	19·78	...	19·78
Na_2O	14·53	...	14·53	14·53
B_2O_3	65·20	32·80	32·64	65·44
Total ...	99·51	52·58	47·17	99·75

Possible Composition.

Sodium pyrofluoborate $NaF.B_2O_3$	52·58
,, pyroborate $Na_2O\ (B_2O_3)_2$	47·17
Total	99·75

The B_2O_3 figure obtained by calculation, 65.44 per cent., checks closely the determined figure 65.20 per cent. c.f. Analysis of sodium metafluoborate, batch 239.

The analysis of the above products indicates a loss of fluorine during their preparation. In an attempt to overcome this loss further batches of sodium metafluoborate $(NaF)_2.B_2O_3$, were prepared under varying conditions and the fluorine determined.

PREPARATION OF $(NaF)_2.B_2O_3$, BATCH 255.

9.05 gms. of NaF (prepared in the laboratory) was placed in a Pt. dish with 7.50 gms. of coarsely broken fused B_2O_3 glass (prepared from Boric acid, BDH., AR) and heated in the electric furnace at 960° C. for the shortest possible time until miscible. This took 5 minutes. The fused product was cooled by pouring into a cold Pt. dish and finely ground.

F per cent.—22.3.

Under these conditions, when the time of heating is limited, the amount of fluorine is increased to within 2.43 per cent. of the theoretical.

PREPARATION OF $(NaF)_2.B_2O_3$, BATCH 277.

12.06 gms. NaF (Lab.) was placed in a Pt. dish with 10 gms. of coarsely broken fused B_2O_3 (same reagents as used in batch 255) and heated in the electric furnace at temperatures between 850-960° C. for 20 minutes stirring occasionally. No fumes were noticed on heating. The melt was poured into a cold Pt. dish as before. The product, a white, hard enamel-like substance, was finely ground.

F per cent.—23.19.

Under these conditions the figure for fluorine is 1.54 per cent. lower than the theoretical.

PREPARATION OF $(NaF)_2.B_2O_3$, BATCH 278.

This product was prepared in a similar manner to batch 277 except that the temperature was raised to 960-1040° C. and heated for 5 minutes only until miscible. Fumes were given off. The product was a white, enamel-like substance similar to batch 277.

F per cent.—23.52.

The fluorine figure here is increased to within 1.21 per cent. of the theoretical.

PREPARATION OF $(NaF)_2.B_2O_3$, BATCH 279.

This product was prepared in a similar manner to batch 277 except that the temperature was lowered to 750-850° C. and the mass constantly stirred at this temperature for 30 minutes. No fumes were noticed. The heated mass was pasty and not completely fused. On cooling it did not have the enamel-like appearance of batches 277 and 278.

F per cent.—22.91.

This figure is 1.82 per cent. lower than the theoretical.

In the preparation of these fluoborates the operations preparatory to heating were carried out in the shortest possible time to prevent the introduction of water per medium of the fused boric oxide glass.

The percentages of fluorine obtained were as follows:—

Batch No.	224–5	239	255	277	278	279
F %	16·17	18·75	22·30	23·19	23·52	22·91

These figures show that on limiting the time under the conditions of preparation in batches 277-9 the percentage of fluorine was increased considerably, the maximum figure obtained being 23.52 per cent. on heating 5 minutes. It is generally considered that in the determination of fluorine only about 95 per cent. is recovered, therefore it can be assumed that under the conditions of preparation of batches 277-9 nearly the whole of the fluorine is retained.

The analyses and calculations of batches 239 and 240 suggest that some of the fluorine is replaced by oxygen leaving a mixture of sodium metafluoborate and sodium metaborate in batch 239 and sodium pyrofluoborate and sodium pyroborate in batch 240.

EXPERIMENTS ON FERROUS IRON DETERMINATION WITH THE ABOVE SODIUM METAFLUOBORATES.

EXPERIMENT WITH $(NaF)_2.B_2O_3$, BATCH 239.

Exp.	Garnet 735/33.	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
244	·3	1·5	900 960°C.	20′	·0956	31·87	Similar to Exps. 224 5.

EXPERIMENT WITH $NaF.B_2O_3$, BATCH 240.

Exp.	Garnet 735/33.	NaF B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
243	·3	1·5	900—960°C.	20′	·0923	30·76	Dark green fusion. Similar to borax fusion. Faint yellow solution.

EXPERIMENT WITH $(NaF)_2.B_2O_3$, BATCH 279.

Exp.	Garnet 735/33.	$(NaF)_2$ B_2O_3	Temp.	Time.	FeO.	FeO.	Conditions.
					gms.	%	
289	·4	2·0	900 960°C.	15′	·1264	31·60	Similar to Exps. 224 5.
291	·45	2·25	do.	15′	·1417	31·49	do. do.

The mean figure for Experiments 244, 289 and 291 with sodium metafluoborate is 31.65 per cent. FeO. This checks the previous mean figure of 31.69 per cent. FeO.

SUMMARY.

A survey of the methods in the literature at the disposal of the author is presented with the reasons necessitating the development of a new method. The hydrofluoric and sulphuric acid methods are not satisfactory with certain minerals, *e.g.*, tourmaline, on account of their refractoriness to these acids.

The complete experimental work carried out is described and consists of the investigation into the effect upon the decomposition of almandine garnet of various fluxes by fusing and sintering. The fluxes used were:—KOH, NaOH, KF, NaF, KHF_2, CaF_2 $Na_2B_4O_7$, $(NaF)_2.B_2O_3$, $NaF.B_2O_3$. Satisfactory results were obtained with sodium metafluoborate $(NaF)_2.B_2O_3$.

A consideration of the preparation, analysis and constitution of the fluoborates is presented with the determination of the ferrous iron values of almandine garnet by fusion with these substances.

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9.—CONTRIBUTIONS TO THE FAUNA OF ROTTNEST ISLAND. VIII. APOIDEA.

WITH DESCRIPTION OF NEW SPECIES.

By TARLTON RAYMENT.
Communicated by L. Glauert.

Read: 13th March, 1934. *Published*: 4th December, 1934.

So little work has been done on the Hymenoptera of Australia that even moderate collections reveal new species, and the Rottnest series, though small, are no exception to this rule. The island is so close to the mainland, that one could hardly expect to find any great departure from the mainland forms, yet there are differences, but until the insects of Western Australia are known better, it is not wise to attach much importance to the variations as indicative of specialization due to a change of ecology. Any very large series of mainland species exhibits differences, which is not surprising when one remembers that perfect stability of form must be exceedingly rare in the evolutionary scheme.

Professor W. M. Wheeler, when he last visited Australia, told me that when collecting in America one would often obtain large numbers of one species, but here it was different, one could obtain numerous bees, but they would be of many genera and species. I partly agree with him, but point out that should the collector just happen to obtrude during a certain phase of the life-history, then he will most certainly obtain a preponderating number of say, males of one species, whereas, should he be a little later, hardly one male would be caught. The collections surveyed in this paper contain very large series.

I have been able to study the bees of the island owing to the courtesy of Mr. L. Glauert, Curator of the Museum at Perth, who collected the specimens and to whom I am indebted for a reprint of Alfken's paper on Hymenoptera of Western Australia.

On the ground of economy, the historical references have been omitted.

Order *HYMENOPTERA.*

Suborder *HETEROPHAGA.* Superfamily APOIDAE.

Division *COLLETIFORMES.* Family HYLAEIDAE.

Hylaeus obtusatus Smith.

A very large series of females varying much in size. Some having a yellow spot on the tegulæ, but all with short jaws approaching those of *Pachyprosopis.*

A large series of males indistinguishable from those of the mainland. (February, 1933.)

Hylaeus cognatus Smith.

Four females identical with those of the mainland. One *Hylaeus* male so exceedingly close to *H. cognatus* that I do not separate it. (February, 1933.)

Hylaeus elongatus Smith.

One male which answers to Smith's description; this is very close to *H. cognatus* Sm.

Turnerella glauerti, sp. nov.

Female.—Length, 3mm. approx. Black and Yellow.

Head large, quadrate from front, scattered minute punctures; face to beyond antennal insertion butter-yellow; frons with a delicate sculpture; clypeus short, but wide; supraclypeal area large; vertex black, the junction of the colour "countercharged," *i.e.*, the yellow impinges on the black with the same pattern as the black on the yellow; compound eyes black, anterior margins parallel; genæ yellow, upper portion black; labrum yellow, a few white hairs; mandibulæ yellow, reddish apically; antennæ with yellow scapes, flagellum yellow beneath, black above.

Prothorax black, with irregular dull-yellow marks; tubercles yellow; mesothorax, scutellum, postscutellum and metathorax shining black dorsally, a minute sculpture, scattered minute punctures, mesothorax with obscure yellowish patches anteriorly; metasternum with dark patch; abdominal dorsal segments blackish, margins of one and two yellowish; ventral surface of entire insect butter-yellow.

Legs yellow, hind tibiæ more or less suffused with black; tarsi of hind legs suffused with blackish; claws reddish-amber; hind calcar white (as the insects are on cards this cannot be studied); tegulæ yellow; wings hyaline; nervures dark-brown, rudiments of the second cubital cell in the form of stumps; cells: the radial very large; pterostigma large, brown; hamuli cannot be studied.

Locality.—Rottnest Island, Western Australia (March, 1933).

Type in the collection of the Perth Museum.
Allies: *T. doddi* Perk., which has the basal cavity of the abdomen yellow. This was described from Queensland.

Euryglossina hypoxantha, sp. nov.

Female.—Length 4mm. approx. Black and yellow.

Head very wide, yellow; face with a microscopical striation and scattered small punctures; frons with the black of the vertex meeting the yellow along a suffused edge; clypeus yellow; excessively short; supraclypeal area very prominent, yellow; vertex with a black (or suffused with blackish on some) parallelogram; compound eyes reniform, black; genæ yellow; labrum yellow; mandibulæ yellow, with red tips; antennæ inserted very low down, amber, first segment of flagellum large, segments wider than long.

Prothorax yellow, but suffused with blackish above; tubercles yellow; mesothorax yellow, but dorsal surface suffused with blackish; minute close punctures and cancellate sculpture; scutellum and postscutellum black on male (suffused with blackish on female); metathorax yellow, but suffused with black on dorsal surface; abdominal dorsal segments black on male (with suffused bands on female), long white hair apically, a few short stiff hairs.

Legs yellow, tarsi amber, hind tarsi darkest; claws reddish; hind calcar pale-amber; tegulæ pellucid; wings hyaline, iridescent; nervures pale-amber, basal arched; cells: second cubital a trapezium; pterostigma large, amber; hamuli five, exceedingly weak.

Locality.—Rottnest Island, Western Australia (March, 1933).

Type in the collection of the Perth Museum.

Allies: *E. hypochroma* Ckll, which has a black head. The new species has the whole of the dorsal surface of the males black, or suffused with blackish on females.

Euryglossina flaviventris Cockerell.

A series of females indistinguishable from specimens from the type locality, Mt. Hule, Healesville, Victoria. This is a great extension of range, and since the flight of these bees is very limited, it is plain that they could not have crossed the stretch of water now separating the island from the mainland.

Recorded also from Brisbane, Queensland. (March, 1933).

Euryglossina parazantha, sp. nov.

Female.—Length 5.5mm. Black and yellow.

Very like *E. hypozantha,* but the tegument is coarsely tessellate, whereas that of *E. hypoxantha* is exceedingly finely striate. The black of the dorsal surface is intense, not at all suffused, extends to the thoracic sterna, and is marked about the pleura with large patches of yellow. The facial foveæ are short, straight, and extend below the black as fine black lines, while the yellow of the face extends up along the orbital margin as a fine yellow line. The foveæ of *E. hypoxantha* are very long, and incurved until they almost touch the lateral ocelli. (March, 1933).

Euryglossina microdonta, sp. nov.

Female.—Length, 4mm. approx. Black.

Head large, but not quadrate, bright; face-marks nil; frons with a delicate sculpture, and scattered fine punctures; clypeus short but wide, punctures more evident and closer, anterior margin with three small teeth, the middle one being minute; supraclypeal area and vertex with similar sculpture; compound eyes black, reniform; genae minutely striate; labrum amber; mandibulæ amber tipped with red, broad, somewhat truncated; antennae black, flagella amber beneath.

Prothorax finely striate; tubercles yellow with a black spot; mesothorax coriaceous, minute obscure punctures, a few short white hairs; scutellum, postscutellum and metathorax of similar sculpture; abdominal dorsal segments microscopically transversely lineolate; ventral segments similar.

Legs black, knees and anterior tibiae yellow; tarsi somewhat suffused with blackish, a few short white hairs; claws reddish; hind calcar cannot be studied; tegulae pallid, with a dark dot; wings subhyaline; nervures dilute sepia; cells normal; pterostigma large, dilute sepia; hamuli cannot be studied.

Locality.—Rottnest Island, Western Australia. (March, 1933.)

Type in the collection of the Perth Museum.

Allies: Approaches *E. fultoni* Ckll, which was described from Purnong, South Australia, and which has all the tibiae yellow, but it lacks the clypeal teeth. Neither is typical of the genus.

Euryglossae Smith.

Those with a metallic head and thorax, black abdomen, and reddish legs may be separated by the following:—

KEY.

Clypeus green.	
Mandibles yellow.	**E. inconspicua lutea** subsp. nov.
Clypeus black.	1.
1. Abdomen black.	**E. inconspicua** Ckll.
Mandibles dark red subapially.	2.
2. Head and thorax bluish.	**E. walkeriana** Ckll.
Flagellum dark.	3.
3. Mandibles dark amber.	**E. subinconspicua** Raym. (M.S.).

Euryglossa inconspicua lutea, subsp. nov.

Female. Length, 5.5mm. approx. Green and black.

Head green, shining; face-marks nil; frons tessellate, scattered shallow punctures; clypeus polished green, scattered deep punctures; supraclypeal area similar, pyramiform, a fine carina reaching the median ocellus; vertex with a dark-purple mark on orbital margin; compound eyes reniform, blackish; genae with long, loose white hair; labrum blackish; mandibulae butter-yellow, red apically; antennae black above, flagellum ferruginous beneath.

Prothorax green; tubercles black, with fringe of white hair; mesothorax bronze-green, teesellate, a few punctures, a few white hairs; scutellum similar; postscutellum darker, with finer sculpture; metathorax dark bluish-green, tessellate shining, with long white hair laterally; abdominal dorsal segments black, with hind margins broadly and laterally light luteous, a few white hairs; ventral segments similar.

Legs greenish-black, knees and tibiae light-ferruginous, white hair; tarsi light-ferruginous; claws reddish-amber; hind calcar pale-amber; tegulae pale-amber; wings hyaline, iridescent; nervures amber, second recurrent, if continued up, being parallel with the second intercubitus; cells: second cubital longer than high, basal and apical margins of equal length; pterostigma amber; hamuli six, weak.

Locality.—Rottnest Island, Western Australia (March, 1932.)

Type in the collection of the Perth Museum.

Allies: *E. walkeriana* Ckll, which is bluish, with dark mandibles. This was described from Tasmania, and I have collected it at Croydon, Victoria.

Family COLLETIDAE.

Paracolletes amabilis Smith.

One female, typical in all characters.

Paracolletes friesei Cockerell.

Male.—Length, 8mm. approx. Blue.

Head dark-blue, bright, with loose, long, white hair; face-marks absent; frons longitudinally striate; clypeus black, with purple tints, large scattered punctures; supraclypeal area blue; vertex with fuscous hair; compound eyes blackish, reniform; genae greener, with long white hair; labrum blackish; mandibulæ blackish, with beautiful purple tips; antennæ black, flagellum reddish at apex, second basal segment somewhat flattened and dilated.

Prothorax not visible from above; much white hair beneath; tubercles with white hair; mesothorax greener than head, large scattered punctures on a rough sculpture, a dense coat of bright-orange or fulvous hair; metathorax blue, with several transverse striae; abdominal dorsal segments bluish-purple, hind margins broadly depressed, and narrowly lighter, coarse scattered punctures, scattered white hair; apex with fuscous hair; ventral segments blacker, with white hair.

Legs black, with black and white hair; tarsi black, white hair with golden tints; claws amber; hind calcar blackish, large; tegulae piceous, polished; wings hyaline; nervures brownish; cells, second cubital contracted at apex; pterostigma brown; hamuli nine, of moderate development.

Locality.—King George's Sound, also Rottnest Island, Western Australia. (February and March.)

Allotype in collection of the Author.

Allies: *P. plumosus* Sm., which is bluer on the mesothorax.
Paracolletes friesei Ckll. syn. *P. fervidus* Friese.

Several females rather larger than the type to which they otherwise conform very well. Described from King George's Sound.

Paracolletes minutus Cockerell.

A vary large series of males, typical in all characters, and as many females, which confirm Meade Waldo's suggestion that *P. halictiformis* Ckll is the other sex.

A description of the Rottnest Island species is appended.

Paracolletes minutus Ckll.

Female.—Length, 7.5mm. approx. Black.

Head circular from front, shining; face with long loose white hair laterally; frons densely and closely punctured; clypeus convex, close coarse punctures, a few slender hairs; supraclypeal area rising to a fine carina, polished at apex; vertex sharply developed with short fuscous hair; compound eyes claret-brown, reniform; genæ almost rugose; labrum black; mandibulæ red, black basally and apically; antennæ black, obscurely lighter beneath.

Prothorax not visible from above; tubercles fringed with white hair; mesothorax with dense coarse punctures, shining, and dull-white, moss-like hair; scutellum similar, but hair on disc darker; postscutellum coarsely punctured, with a tuft of long white hair stained with drab in centre (in some specimens a slight prominence); metathorax rugose, coarsely so, a few white hairs laterally; abdominal dorsal segments with apical margins broadly brown, two, three and four with narrow fringes of short white hair; closely punctured; apex with fuscous hair; ventral segments brown, otherwise similar to dorsal surface.

Legs brownish-black, with white hair, scopa on hind tibia fuscous on outer surface; tarsi redder, with yellowish hair; claws reddish; hind calcar reddish, with eight long fine spines; tegulæ pellucid brown; wings subhyaline; nervures brownish; cells as in female; pterostigma amber, with darker margin; hamuli seven, weakly developed.

Locality.—Rottnest Island, Western Australia (December, 1930, 1932).

Allotype in the collection of the Perth Museum.

Allies: *P. punctatus* Sm. which is delicately punctured on metathorax, with bright yellow hair on legs and fringes of abdomen.

Paracolletes subminutus, sp. nov.

Female.—Length, 9mm. approx. Black.

Head transverse, not very bright, numerous punctures of various sizes; frons finely punctured, polished; clypeus with a minute sculpture, duller, with larger irregular shallow punctures; supraclypeal area polished, with a fine carina reaching and enclosing the median ocellus; vertex with hair slightly yellowish; compound eyes with long pale hair; labrum black; mandibulæ long, black with obscure red apically, the inner tooth very small; antennæ dark-brown above, obscure red beneath at extreme apex.

Prothorax not visible from above, black; tubercles black, fringed with pale hair; mesothorax polished with numerous fine shallow punctures, long pale hair; scutellum similar to mesothorax; postscutellum rougher, dull, with an obscure elevation and a tuft of white hair; metathorax has the enclosed area with weak transverse striæ; abdominal dorsal segments bright, hind margins broadly pallid, and separated from the black with a red line, the segments are finely and sparsely punctured, three and two with broadly interrupted bands of white hair, four with white hair, five and six covered with hair of a reddish-gold tint, the last with a dark-red naked area; ventral segments showing more red, and each has a white fringe.

Legs blackish, the tibial scopa long, white within and stained without; tarsi with yellowish hair beneath, white above, claws bifid, dark-red; hind calcar ferruginous, with ten slender spines; tegulæ polished, dark-reddish; wings very slightly yellowish; anterior 6mm. nervures dark-brown, basal slightly arched, just short of nervulus, first recurrent meeting the second cubital cell at its anterior third; all had a stump arising from the discoideus nervure as though vestigial of a fourth discoidal cell; cells: the second cubital greatly contracted at its apex; pterostigma dark-brown, of moderate development; hamuli seven, weakly developed.

Locality.—Swan River, Western Australia (collector not known).

Type in the collection of the author. Two specimens from Rottnest Island in the collection. (October, 1931).

Allies: *P. nanus* Sm. which has black hair at apex of abdomen; *P. nicholsoni* Ckll. with impunctate basal segment; *P. punctatus* (Sm.) with fulvous hair-bands on abdomen. These could be the females of *P. pusillus* Ckll.

Paracolletes submacrodontus, sp. nov.

Male.—Length, 11mm. approx. Black.

Head with facial quadrangle longer than wide; face with dull-white hair; frons shining, with weak punctures; clypeus rough, with numerous shallow punctures; supraclypeal area with large, distinct punctures; vertex nearly impunctate, with fewer pale hairs; compound eyes reniform, claret-brown; genæ finely striate, sparse coarse punctures; loose white hair; labrum black; mandibulæ black, a reddish patch subapically; antennæ long, submoniliform, black above, obscure reddish beneath.

Prothorax not visible from above; tubercles with white loose hair; mesothorax smooth, shining, scattered shallow punctures, a dense covering of grey hair tipped with fuscous; scutellum with two large tubercles; postscutellum with a large tubercle; metathorax with a large highly-polished area enclosed with a beaded margin, outside of which are scattered punctures and white hair; abdominal dorsal segments black, apical margins broadly reddish-amber, with a thin, loose fringe of long pale hair; numerous fine punctures and shorter black hair; apex with black hair; ventral segments similar.

Legs dark-reddish on femora and tibiæ, but black on trochanters and coxæ; long pale hair; tarsi dark-reddish, white and golden hair; claws reddish; hind calcar reddish, fine long serrations; tegulæ reddish-black, polished; wings darker apically; nervures brown, first recurrent entering second cubital at middle; cells: second cubital quadrate, radial truncate; pterostigma small, dark-brown; hamuli fifteen, strongly developed.

Locality.—Rottnest Island, Western Australia. (February, 1933).

Type in the collection of the Perth Museum.

Allies: *P. microdontus* Ckll. which has black legs, and no tubercles on scutellum; *P. macrodontus* Raym. which has a very acute tooth on the post-scutellum.

Division *ANDRENIFORMES.*

Family HALICTIDAE.

Halictus pulvitectus Cockerell.

A large series of males and females, smaller than the type which was described from Eaglehawk Neck, Tasmania. A new record for the State, and which greatly extends the range of this species. Compared with specimens from Clovelly, New South Wales, these are larger with antennæ lighter beneath. (October, 1931, December, 1932.)

Halictus orbatus Smith.

A bee that may prove to be the male of this species which also was described from Tasmania.

Halictus victoriae Ckll.

A very large series of females and males. Since a number are gummed on each card, there may be *H. veronicae* among them. I have always taken these together at Sandringham, Victoria, from where they were described. In any case, these two species are difficult to separate. The males are the undescribed sex, and I append a description which shows how close to *H. veronicae* it is.

Halictus victoriae Cockerell.

Male.—Length, 4mm. approx. Green.

Head wide, shining; face with scattered loose white hair; frons closely punctured; clypeus polished, anterior half bracket-shaped, cream, posterior green, a few punctures; supraclypeal area polished, with fine punctures; vertex with strong transverse striæ, about three in number; compound eyes claret, subreniform; genæ finely punctured, with long, loose plumose hair; labrum cream-coloured; mandibulæ acute, creamy-yellow tipped with red; antennæ black, beneath the flagellum is creamy-orange, except the three apical segments which are black.

Prothorax not visible from above; tubercles greenish, with a thin fringe of white hair; mesothorax coppery-green, polished, a few punctures, a few white hairs; scutellum similar, postscutellum blue-green, rougher; metathorax greener, with partly radiating, partly anastomosing rugæ, a few white hairs; pleura with long white hair; abdominal dorsal segments polished, fine punctures, margins very narrowly ferruginous, seventh ferruginous; ventral segments similar, with considerable white hair.

Legs with dark prismatic femora, anterior tibiæ reddish, with white hair; tarsi: basitarsi creamy, others pale-ferruginous; claws reddish-amber; hind calcar creamy; tegulæ pellucid, with brown spots; wings prismatic, hyaline; nervures pale-amber, outer recurrent and intercubitus faint; cells normal for *Chloralictus*; pterostigma pale-amber, with dark-brown margin; hamuli six, very weak.

Locality.—Sandringham, Victoria, March (Rayment); Rottnest Island, Western Australia. (December, 1931, and March, 1933.)

Cotypes in the collection of the Museum and the author.

Allies: *H. veronicae* Ckll. which has ferruginous legs; *H. purnongensis* Ckll. which has a piceous abdomen.

In Victoria, mating on flowers of garden *Veronica.*

Family MELECTIDAE.

Crocisa waroonensis Ckll.

Two females. Specimens from the Swan River, on the mainland, often show a bluish powdery bloom over the entire insect, but on these island specimens the bloom is entirely absent. (January, 1932.)

Family ANTHOPHORIDAE.

Anthophora zonata Linn.

Two females with the hair of the thoracic disc much bluer than specimens from the River Murray, in Victoria, when the hair is almost fulvous. (January, 1932.)

Anthophora cingulata Fabr.

A series of females. They are unlike most *cingulata* in my collection, but agree in a general way with females from Sydney. Viewed from the rear the abdominal bands are almost golden, but viewed from above the bands are more or less bluish to green, as described by Professor Cockerell for *A. adelaide.* They have a close resemblance to females from Tarnagulla, in Victoria. (January, 1932, 1933.)

Anthophora adelaidae Cockerell.

Female.—Length, 12mm. approx.

Head transverse, black; face with pale-yellow hair (Sydney specimen redder); frons with close punctures; clypeus with a creamy-yellow ⊥ reversed, the apex of the stem truncate (acute in Sydney specimen) large punctures (closer on Sydney bee); supraclypeal area with a long thin mark rising to a dome in the middle; vertex with golden hair; compound eyes greenish; genæ with palest-blue hair; labrum cream, white hair; mandibulæ cream, black tips; antennae black; (scape of Sydney bee with a small yellow mark).

Prothorax not visible from above; tubercles black; mesothorax black, closely punctured, with a dense covering of a lively light fulvous hair, mixed with a few black ones; scutellum and postscutellum similar; abdominal dorsal segments black, densely punctured, with appressed black hair; margins with wide hair-bands which, viewed from the rear, appear golden, from above they are more or less greenish-blue; apex with black hair. (Fourth and fifth margins are crenulate in the Sydney bee, but these may be adnormal.)

Legs black, pale-blue hair; tarsi black, some pale-blue hair on basitarsi; claws black; hind calcar blackish; tegulae apricot-colour, with pale yellow hair; wings clear; pterostigma dark-brown; hamuli twenty-one, strongly developed.

(The Sydney bee may not be conspecific.)

Locality.—Rottnest Island, Western Australia. Sydney, New South Wales, P. Whiteley.

Allotype in the collection of the Perth Museum.

Allies: *A. zonata*, Linn., which is smaller. This is a very difficult group, and needs a critical revision, for apart from the yellow face-marks there are few distinguishing characters. The species was described from the Adelaide River.

Division MEGACHILIFORMES.

Family MEGACHILIDAE.

Megachile chrysopyga Smith.

A large series of males and females, which shows some variations in size; females 11-14mm., males 10-12mm. The hair of the face in the males ranges from cream to dark-red, in the females the red colour does not change, but the quantity does. On the Island specimens the apical hair patch of the abdomen is larger, and varies in colour, while the median apical tooth of the male may be acute and long, or obtuse and short. (April, 1930, January, 1932, February, 1932, March, 1932, April, 1930.)

Megachile erythropyga Sm.

One typical male. (February, 1931.)

Megachile preissi Ckll.

Labelled by Preiss "Eastern Australia"; but my specimen was collected in the Swan River, Western Australia. *M. clypeata* has the tegument of the sexth segment red, and the clypeus lacks the long median tooth of *M. Preissi*, the tegment of which is black on the sixth segment.

Megachile clypeata grandis, subsp. nov.

Female.—Length, 8mm. Black.

A large robust form of the species which measures only 6mm. and is found also on the Island. I should have hesitated to separate these but for a slight difference in the clypeal teeth. The compound eyes of both species and subspecies exhibit prominent hairs between the facets. (January, 1932.)

Megachile rottnestensis, sp. nov.

Male.—Length, 9mm. approx. Black, red legs.

Head wide, closely punctured; face covered with dence long white hair; frons closely punctured; clypeus closely and coarsely punctured; margin quadridentato, the median teeth acute; supraclypeal area similar; vertex

almost rugoso-punctate, a few blackish hairs; compound eyes slightly converging below; genae coarsely punctured, a few long white hairs; labrum black; mandibulae black, rugose, a few long yellowish hairs; antennae black, flagellum reddish beneath.

Prothorax not visible from above; tubercles black, with long white hair; mesothorax closely and coarsely punctured, a few white hairs; scutellum and postscutellum similar; metathorax rugose at base only; abdominal dorsal segments with margins depressed, coarsely punctured, red maculae laterally, four with a thin, complete fringe, others with a lateral tuft, apex with eight, strong, obtuse teeth, more or less conjoined, and beneath these two long large black projections almost hidden in white hair, three with a large black tooth laterally; apex with appressed white hair; ventral segments largely red, with coarse punctures, a few white hairs.

Legs with coxae, trochanters and median and hind femora black, anterior femora and all tibiae red, with white hair; tarsi darker, with hair inclining to yellow; claws reddish-amber; hind calcar amber; tegulæ dark-reddish, closely punctured, a few white hairs; wings subhyaline; cells normal; pterostigma obsolete; hamuli eleven.

Locality.—Rottnest Island, Western Australia (December, 1931.)

Type in the collection of the Perth Museum.

Allies: *M. serricauda* Ckll. which has on the basitarsus of the anterior legs a large groove; but the apex of the abdomen lacks the two large black, widely separated lobes of the new species.

Megachile subremotula, sp. nov.

Female.—Legnth, 10mm.. approx. Black.

Head transverse, closely punctured; face with glistening white hair at sides; frons duller, and closely punctured; clypeus closely punctured, but no median raised line as in *M. remotula*; lower edge with three small shining nodules around a small indentation; vertex with a few short dark hairs; compound eyes converging slightly below; genae closely punctured, with long white loose hair; labrum black; mandibulæ black, and broad, with some white hair; antennæ black, obscurely lighter beneath.

Prothorax not visible from above; tubercles black, with a thick fringe of white hair; mesothorax closely punctured, a few short pale hairs; scutellum with a lateral spot of white hair; postscutellum similar to mesothorax; metathorax smoother, with long white hair laterally; abdominal dorsal segments shining, closely punctured, each with a median depression, one with a tuft of white hair, laterally, two, three and four with narrow bands of white hair, interrupted dorsally, five apically and six entirely, covered with appressed red hair; ventral segments with a white scopa.

Legs black, with white hair; tarsi hind tarsi obscure amber; hair yellowish; claws red, simple; hind calcar pale-amber, with the apical claw of *M. remotula*; tegulae piceous, closely punctured, a tuft of white hair; wings subhyaline; nervures dark-brown; cells normal; pterostigma dark-brown; hamuli thirteen, strongly developed.

Locality.—Rottnest Island, Western Australia (December, 1931.)

Type in the collection of the Perth Museum.

Allies: Very close to *M. remotula* Ckll., which is larger, 12mm., with black hind calcar and tarsi.

Division XYLOCOPIFORMES.

Family CERATINIDAE.

Exoneura pictifrons Alfken.

Professor Cockerell (1930) thought that his *E. angophorae occidentalis* might be the females of Alfken's species, and the large series of females, with two males, confirms the Professor. Alfken's name has seven years priority. Compared with mainland specimens, the island males are much larger, and more robust; the red abdomen being darker, and the yellow-face-marks slightly different.

The females present the same variations as those of the mainland; the red stripe of the antennae being yellow on some, and obscure red on others; the clypeus more or less suffused with reddish, or else quite black; the abdominal bands varying in number and intensity of colour. (November, December, January, February.)

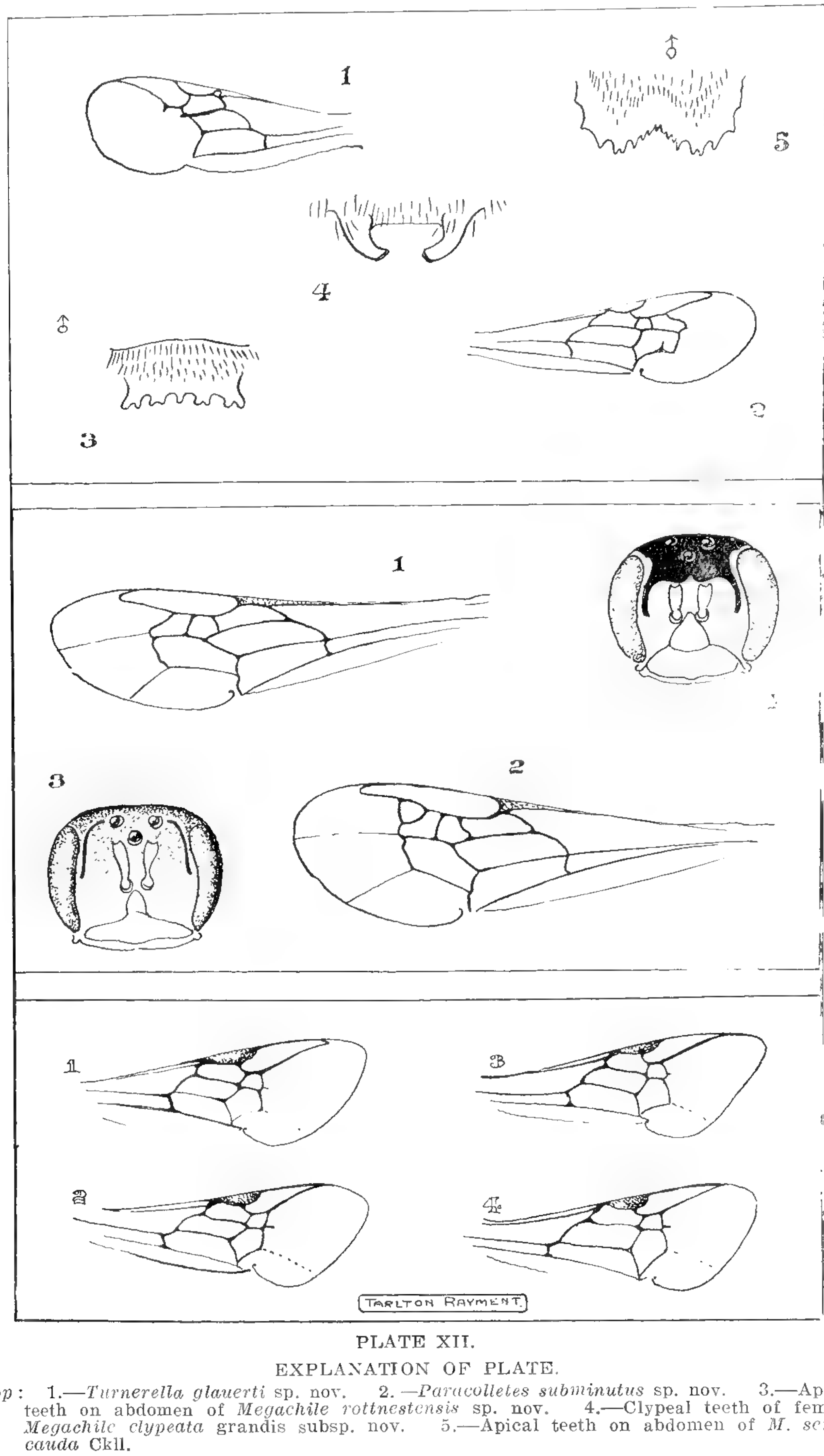

PLATE XII.

EXPLANATION OF PLATE.

Top: 1.—*Turnerella glauerti* sp. nov. 2.—*Paracolletes subminutus* sp. nov. 3.—Apical teeth on abdomen of *Megachile rottnestensis* sp. nov. 4.—Clypeal teeth of female *Megachile clypeata* grandis subsp. nov. 5.—Apical teeth on abdomen of *M. serricauda* Ckll.

Centre: Normal wing neuration for *Trichocolletes* (*T. dowerinensis* Raym.). 2.—Abnormal neuration of *T. tenuiculus* Raym. (male). Note the four cubital cells. 3.—Front view of head-capsule of *Euryglossina hypoxantha* sp. nov. Note the incurved foveæ. 4.—Front view of head-capsule of *E. paraxantha* sp. nov. Flagella not shown.

Lower: 1.—Anterior wing of *Euryglossa subinconspicua* Raym. (M.S.). 2.—*E. inconspicua lutea* subsp. nov. 3.—*E. inconspicua* Ckll. 4.—*E. walkeriana* Ckll. Note the angles of the recurrent nervures and the form of the second cubital cells.

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10.—NEW SPECIES OF CHITONS FROM BROOME, WESTERN AUSTRALIA.

By EDWIN ASHBY, F.L.S., AND BERNARD C. COTTON, Conchologist, South Australian Museum.

(A contribution in part from the South Australian Museum.)

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Communicated by L. Glauert.

INTRODUCTION.

Dr. William J. Clench, Curator of Molluscs of the Museum of Comparative Zoology at Harvard College, Mass., U.S.A., sent to one of us all the Polyplacophora collected by Mr. H. L. Clark on the last Australian Expedition sent out by that Museum, together with some collected previously. Thanks are due to Dr. Clench for giving us the opportunity to examine these specimens from an area so little worked, and for the donation of four specimens to the Ashby Collection in the South Australian Museum. Amongst those taken at Gantheaume Point, Broome, are four new species described hereafter. Of those taken, only three examples belong to the somewhat restricted genus *Callistochiton* and it is astonishing to find that they represent three distinct and new species.

Discussion on the retention of the name Callistochiton.

The genus *Callistochiton* is defined by Pilsbry (Man. Con. Vol. 14, p. 260) and diagnosed by the peculiar character of the insertion plates which are "festooned, being curved outward at the ribs and slit there, thickened outside at the edges of the slits, the latter corresponding in position to the ribs of the outer surface." The genus *Lophochiton* Ashby, has the insertion plates similar to an *Ischnochiton* without any festooning at the slits. Hull overlooked this important feature and placed *Lophochiton granifer* Hull under the genus *Callistochiton* on its external characters only. Iredale and Hull propose to separate the Australian *Callistochiton* from the American and introduce for the Australian group a new genus *Callistelasma*. We consider that their definition does supply adequate data for such generic separation and we are awaiting the receipt of specimens of the type species of Dall's genus *Callistochiton*, when we hope critically to study and compare the two groups.

Callistochiton broomensis, sp. nov.

Pl. XIII., fig. 3.

General appearance. (Dry example).—Oblong, elongate, valves 2 to 7 equal width, medium elevation, arched not carinate, end valves and lateral areas decussated with conical nodules, spaced and arranged in riblets. Colour avellaneous (Ridg. XL.). Girdle broad, clothed with minute scales.

Head valve.—Decorated with ten complete and eight intercalated conically nodulose riblets, the ten riblets continued to the apex, anterior slope curved but steeper at the apex. Interstices minutely subgranulose.

Median valve.—Arched, not carinated, dorsal area covered with a network sculpture; pleural area, with about nine longitudinal rows of coarse, spaced conical grains, the interstices the same width as the grains, and if granulose at all, subgranulose; lateral area is deeply grooved down the centre almost from the jugum (or dorsal ridge) with a double row of spaced grains on either side. On the posterior margin the nodules are broad and spade shape, not conical.

Tail valve.—Mucro defined, central, posterior portion rather flat, radial rows similar to anterior valve 19; anterior portion decorated similar to the pleural areas except the grains are smaller.

Girdle.—(Dry) .2mm. wide and a little less in front of head valve; densely clothed with non-striate scales which are set erectly, closely packed, exposed portion minute and slightly bent over.

Measurements.—Shell curled and bent, not disarticulated, estimated 20mm. x 10mm. of which the exposed shell occupies one half only.

Holotype in Ashby Collection, Reg. No. D.1073. S.A. Museum.

Habitat.—Gantheaume Point, Broome, W.A. (Coll. U.S.A. Exped.)

Callistochiton clenchi, sp. nov.

Pl. XIII., fig. 1.

General appearance. (Dry example).—Oblong, not straight sides as in *C. broomensis* but greatest width reached on valves four and five; subcarinate, side slope curved, elevation medium; end valves and lateral areas ornamented with nodulose ribs; pleural areas with highly raised, very narrow granulose longitudinal ribs, no bridging; net-work sculpture confined to dorsal area. Colour wood brown (Ridg. XL.).

Head valve.—Decorated with fourteen complete (often bifurcating) riblets, which are coarsely nodulose (about twelve nodules in each rib), and continued to the apex; anterior slope straight.

Median valve.—Dorsal area slightly beaked, covered posteriorly with net-work sculpture which in some cases changes into low ribbing anteriorly, interstices minutely granulose; pleural area, ten to eleven very narrow highly raised, beaded, granulose longitudinal ribs which are parallel except at the junction with the lateral where they turn upwards slightly, the interstices occupied by transverse rows of very minute granules that are consistently regular, there is no bridging sculpture; lateral area deeply grooved from the jugum to the outer margin in the centre, with a highly raised, coarsely nodulose rib, mostly bifurcating on either side.

Tail valve.—Mucro defined, subanti-central, posterior slope concave, with fifteen (sometimes bifurcating) nodulose ray ribs, anterior portion similar to dorsal and pleural areas of median valves, except that the transition from dorsal sculpture to pleural is somewhat confused.

Girdle. (Dry).—2½mm. wide, less in front of head valve; densely clothed with non-striate, fairly large imbricating scales, the exposed portions much larger than in *C. broomensis.*

Measurements.—Shell curled, not disarticulated, estimated 19mm. x 12mm., of which the exposed portion of shell occupies 7mm.

Holotype in Ashby Collection, Reg. No. D.10724, S.A. Museum.

Habitat.—Gantheaume Point, Broome, W.A. (Coll. U.S.A. Exped.)

Callistochiton occiduus, sp. nov.

Pl. XIII., fig. 4.

General appearance.—(Dry example) not disarticulated. Oblong, the four central valves of equal width, subcarinate, side slope curved, elevation medium; end valve and lateral areas decorated with strongly raised ribs which are surmounted with widely spaced, shallow, mostly pyramidal nodules; the pleural areas possess coarse, somewhat bent, longitudinal ribbing which is mostly non-granulose, there is no network sculpture or bridging in this area; the girdle is broad and clothed with closely packed somewhat irregular non-striate scales and is distinctly banded. Colour avellaneous mottled with wood brown (Ridgeway), the darker marking forming three bands, a narrow one down dorsal ridge and a broad one on each side.

Head valve.—Slope slightly curved, radial ribs thirteen, highly raised and without bifurcation, surmounted by widely spaced pyramidal nodules, the ribs are not carried to the apex, the interspaces are irregularly, minutely granulose.

Median valve.—Dorsal area with irregular net-work sculpture which changes to longitudinal riblets anteriorly; pleural area decorated with shallow narrow longitudinal riblets which are not parallel with one another but in places much bent and having mostly a sharp upward bend where they join the lateral area; interstices sometimes wide, in others narrow and the surface minutely granulose sometimes transversely arranged but quite irregular in other parts; the longitudinal ribs are often smooth on the ridge, in others showing shallow granules, but very distinct from the straight beaded ribs of *C. clenchi*; lateral areas deeply grooved in the region from jugum to girdle, with one strongly raised nodulose rib on either side, the posterior rib of these pairs just commencing to bifurcate, the nodules are very widely spaced and more or less pyramidal in form, the interspaces similar to those of the pleural area.

Tail valve.—Mucro well defined, anticentral, posterior slope straight and flat, the ray sculpture consisting of separated coarse conical grains, the anterior portion sculptured similar to the pleural areas.

Girdle.—Girdle scales of different sizes, irregularly mixed small and large fairly equally divided, whitish, opaque and at certain angles showing polish, irregularly imbricating, not striate.

Measurements.—Shell dry, somewhat curved and not disarticulated, 22mm. x 10mm. of which the girdle occupies nearly 4mm., less anteriorly; exposed section of shell 7mm.

Holotype in Ashby Collection, Reg. No. D.10725, S.A. Museum.

Habitat.—Gantheaume Point, Broome, W.A. (Coll. U.S.A. Exped.)

Comparisons.

C. broomensis is easily distinguished from any other known Australian *Callistochiton* by the large pointed grains of its sculpture and entire absence of bridging.

C. clenchi by the highly raised parallel longitudinal ribs of the pleural area which are surmounted with the appearance of a string of tiny beads or circular grains, and in the entire absence of bridging.

C. occiduus, from *clenchi* by the widely spaced nodulose sculpture of the lateral area, and the bent, irregular character of the longitudinal ribbing of the pleural area.

Callistochiton meridionalis, antiquus and *periousia* are easily separated from the three new species by their girdle scales, which are minute, and by the extensive bridging occurring in the pleural area. The same distinction holds good with *C. mawlei.* The minute granulose sculpture in the interspaces between the ribs in all the three Broome species is not to be compared with the characteristic "bridging" of most *Callistochitons.*

Callistochiton generos, in its peculiar large-mesh net-work sculpture and in its possessing large, thin, imbricating, highly striate scales, is distinct from the three new species or any other known Australian form.

Ischnochiton (Haploplax) broomensis, sp. nov.

Pl. XIII., fig. 2.

There are two specimens from Broome which prove to be a new and very distinct form, belonging to the subgenus *Haploplax* of the genus *Ischnochiton.*

General appearance.—The larger—selected as holotype—dry, measures 15mm. x 9.5mm. and the smaller 13mm. x 8mm., flat, but slightly carinate, dorsal and pleural areas uniformly, and for the genus, coarsely decussate, the two end valves coarsely, evenly granulose, grains inconspicuously arranged in radial rows, the lateral areas sculptured with sharply cut, broken radial ribs, a somewhat unique feature for any known Australian representatives of the genus *Haploplax.* The holotype has a creamy-white, blushed with pink, dorsal band commencing at the girdle on the head valve and widening posteriorly to almost include the whole of the tail valve except for a terminal darker V-shaped mark; two bluish-gray bands adjoining the girdle on the median valves; the paratype has a U-shaped white mark on the head valve, the rest of this valve dark; dorsal areas of valves two and five, dark; valve six all dark; seven and tail valve creamy-white. In both shells there is pale mottling over the lighter markings. It is evident that in colour markings this species will be as variable and decorative in colour markings as its near ally, *I.* (*H*) *smaragdinus* Angas.

Head valve.—Large and shallow, anterior slope straight, except close to the girdle, where the angle of slope is slightly altered upward; whole shell decorated with irregular, pebble-shaped grains, under lateral lighting shown to be arranged in much broken, irregular, radial riblets numbering roughly about forty.

Median valve.—Dorsal and pleural areas inseparable, decorated with decussated sculpture, much coarser than usual in this subgenus; lateral area with much broken, deeply cut radial ribs numbering six or seven, the interstices irregularly covered with granules tending to obscure the radial ribs which need lateral lighting for observation.

Tail valve.—Elevation exceptionally shallow, mucro well defined, posterior slope concave and decorated similar to the head valve; anterior portion forms about one-third of the valve and has similar decoration to the pleural areas of the median valves.

Inside.—The gills extend from the head to about three-quarters the length of the foot.

Articulamentum.—Whitish with wash of pink at jugum and of blue laterally.

Slits.—Head valve 10, median valves 1/1, tail valve 12; sutural laminae shallow, sinus between broad.

Girdle.—Evenly banded throughout and clothed with polished, pebble-like scales without striae.

Measurements of Holotype.—Whole shell (dry) 15 x 9.5 mm., head valve 2.4 x 5.7mm., median valves 2.5 x 7mm., tail valve 3.2 x 6mm.

Habitat.—Grantheaume Point, Broome, W.A. (Coll. U.S.A. Exped.)

Comparisons.—The coarse sculpture readily distinguishes it from any other *Haploplax*. *Ischnochiton arbutum* Reeve approaches it, but the form of that species from Palm Island, Queensland, merely shows a little radial subobselete ribbing in the lateral areas, broad in proportion to length being almost circular shells. Examples of *I. arbutum* from Cape Yorke (compared with the types in London) are more elevated and have coarser sculpture, but differ from the species under review, not only in their greater elevation, but also the ribs in the lateral area are much less defined and deeply cut. The tail valve in *broomensis* is larger, flatter, and the mucro more posterior than in the case of *arbutum*, the posterior slope is straight and steep in the north coast *arbutum* whereas in *broomensis* it is concave and flat and the anti-mucronal portion much larger.

Iredale and Hull publish a M.S. name of Carpenter's *Lepidopleurus cygneus*, for a single example in the British Museum said to have come from N.W. Australia. The only definition supplied is that the sculpture is less strong than in *I. (H) Arbutum*. As the species under review is shown to have definitely stronger sculpture than *arbutum* we have no grounds for considering it conspecific with *L. Cygneus*.

Isochiton sub. gen. nov.

Girdle scales, canoe or shuttle-shape similar to the genus *Callochiton*, but insertion plates *Ischnoid*; slits in median valves 1/1 sometimes 2. Sculpture, closely packed radial riblets in end valves and lateral areas; pleural areas longitudinally ribbed, slits do not correspond with the ribs in the anterior valve as in *Callistochiton*. Until it is possible to examine the characters of the body and radula this genus may be regarded provisionally as intermediate between the genera *Ischnochiton* and *Callochiton*, but accurate conclusions are impossible from the somewhat imperfect specimens before us. It may be regarded as a subgenus of *Ischnochiton*. Type *Isochiton bardwelli* sp. nov., described below.

Ischnochiton (Isochiton) bardwelli sp. nov. Pl. Fig. 5.

Capt. Beresford Bardwell sent three damaged examples of a new species from Broome. They were labelled *Solvaga recens* Thiele but are quite distinct from that species in sculpture, insertion plates and girdle scales. We have pleasure in naming it after the donor.

General appearance.—Carinated, oval; third and fourth valve broadest laterally, tapering from there posteriorly; end valves and lateral areas decorated with closely packed ray-ribs; jugum, smooth; rest of dorsal areas and pleural areas possess well defined, straight, longitudinal ribs. Colour; anterior valve, dorsal area of median valves and centre of tail valve creamy white, rest of shell dark brown. Both paratypes are cream colour with pale banding on girdle.

Head valve.—Strongly raised, anterior slope steep, concave, decorated with about fifty radiating ribs of varying length, the elevated apex smooth.

Median valve.—Jugum, narrowly wedge-shape and smooth, rest of the dorsal area longitudinally ribbed; pleural area decorated with longitudinal

ribs which are straight, including those in the dorsal area, eight in number; those in the dorsal area half the width of the rest; these ribs are not strictly granulose but closely grooved at right angles to their length; lateral areas possess radiating ribs of varying length grooved transversely with growth lines which increase in number posteriorly until in the post mucronal area of the tail valve the ribs become granulose.

Tail valve.—Mucro anterior, posterior portion of valve straight with a very slight slope and decorated with about fifty radiating granulose ribs; the portion immediately under the mucro steeper and under 20 X magnification rugose; anterior mucronal area is similar to the dorsal and pleural areas of the median valves.

Inside. (Articulamentum).—Head valve fourteen slits, irregular, teeth smooth; *median valves* 1/1 slits, valve four an additional slit on one side; tail valve eleven slits; eaves apparently not spongy, teeth not propped.

Girdle.—Clothed with elongate canoe or shuttle-shaped scales (similar to those in the genus *Callochiton*) but are not imbricating as in that genus, but are mostly exposed for the whole length, commencing parallel to the shell but rapidly changing to a position at right angles to the shell; this arrangement gives an irregular curved disposition of the scales; scales themselves, smooth and polished. This peculiar arrangement of the scales is easily seen under a 65 X magnification, but is not easily distinguished with the ordinary pocket lens. The girdle is 1.5mm. in width.

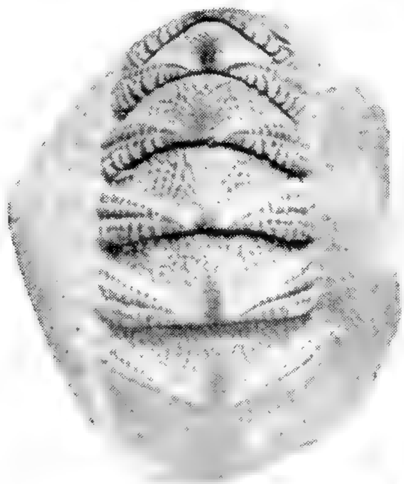
Measurement.—Holotype, whole shell, 11.5mm. x 7mm. (girdle partly missing so should measure a little more). Paratype No. 1, 13.5mm. x 9mm., No. 2, 11mm. x 7.5mm., head valve 5mm. x 2.75mm., median valve (fourth valve) 5.5mm. x 2.5mm., tail valve 4mm. x 2.5mm. The sutural laminæ are only undamaged in the tail valve and these are shallow, anterior edge straight, sinus rather broad. Articulamentum white, tegmentum turned over under the umbo, does not appear sculptured.

Habitat.—Dredged off Broome in about 7 fathoms.

Comparisons. Girdle scales similar to those of *Callochiton mayi,* but the arrangement is different. In *Callochiton* the scales vary from needle-shape to shuttle-shape and are placed at right angles to the longitudinal line of the shell, but in the present species they commence horizontal to the shell then rapidly, somewhat irregularly assume a right angle direction and do not imbricate as in *Callochiton.*

1

2.



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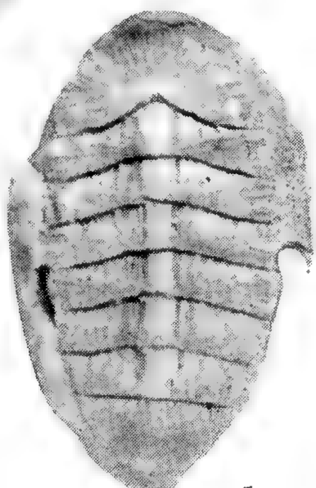

5.

PLATE XIII.

EXPLANATION OF PLATE.

Fig. 1.—*Callistochiton clenchi* sp. nov.
Fig. 2.—*Ischnochiton broomensis* sp. nov.
Fig. 3.—*Callistochiton broomensis* sp. nov.
Fig. 4.—*Callistochiton occiduus* sp. nov.
Fig. 5.—*Ischnochiton bardwelli* sp. nov.

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